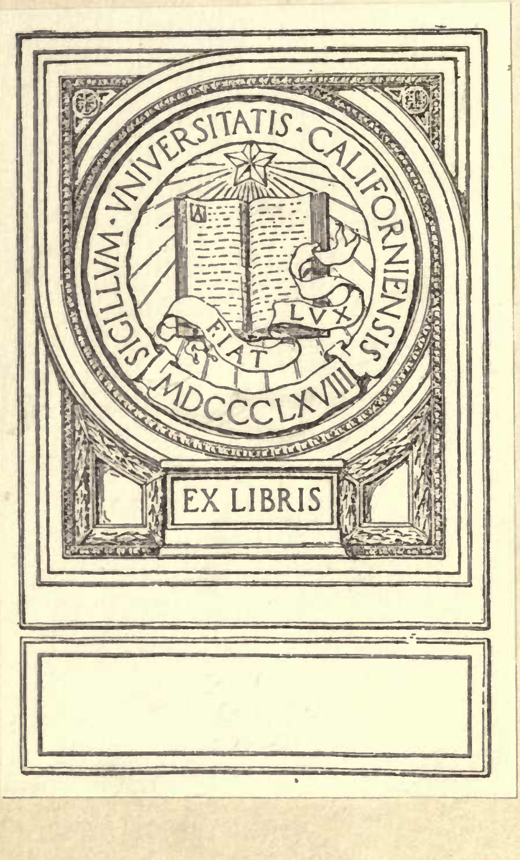
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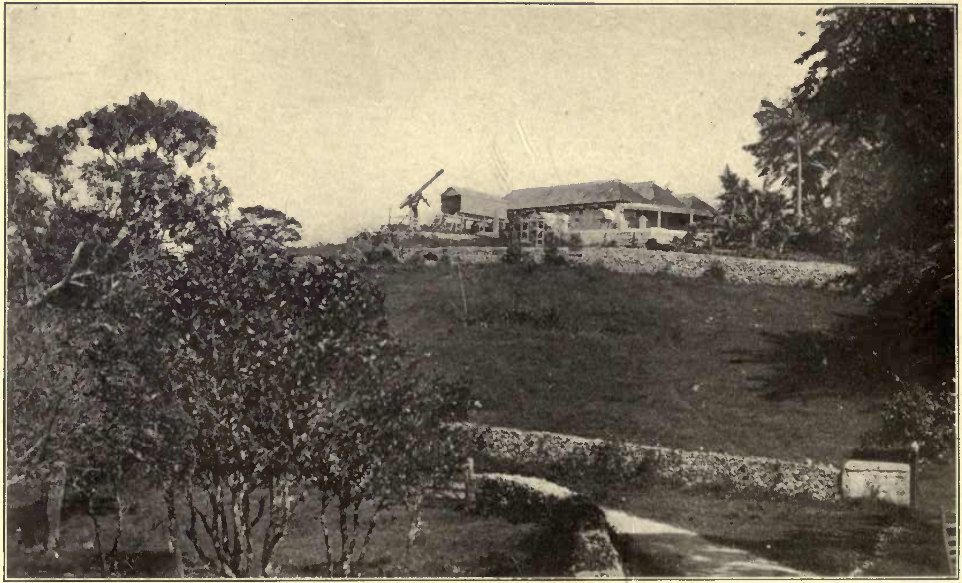

HARVARD ASTRONOMICAL STATION AT MANDEVILLE, JAMAICA

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MARS

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PREFACE

The following list of Collected Papers on Mars contains all those of importance prepared by the author between 1890 and 1914. Excepting the first and the last, they are arranged in chronological order. All have been revised, and some of them shortened. No important additions have been made, yet it is believed that it will be found that they represent very satisfactorily the latest modern views on the physical conditions of the planet's surface.

William H. Pickering.

Mandeville, Jamaica, B. W. I.
August, 1921.

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CONTENTS

CHAPTER PAGE
I. FACTS ABOUT MARS 11
  Peculiarities of the Planet
  The Shifting Marshes
II. PHOTOGRAPHS OF A SNOW STORM ON MARS . . . 21
III. THE GLACIAL PERIOD AND THE PLANET MARS . . 24
IV. COLORS EXHIBITED BY THE PLANET MARS . . . 26
V. CHANGES AND FLOODS ON MARS 42
VI. MARS IN 1892 56
VII. SCHIAPARELLI'S LATEST VIEWS REGARDING MARS . 64
  The Planet Mars by Giovanni Schiaparelli
VIII. THE SEAS OF MARS 97
IX. RECENT STUDIES OF THE MARTIAN AND LUNAR CANALS 103
X. AN EXPLANATION OF THE MARTIAN AND LUNAR CANALS 108
XI. THE DOUBLE CANALS OF MARS 113
XII. THE MARTIAN SNOWS 116
XIII. WHAT WE KNOW ABOUT MARS 120
  The Orbit of Mars
  Gravitation, Water and Atmosphere
  Climate and Meteorology
  Seas, Canals and Lakes
  Duplication of the Canals
  Seasonal Changes
  Is the Planet Inhabited by Intelligent Beings?
XIV. DIFFERENT EXPLANATIONS OF THE CANALS OF MARS . 147
XV. SIGNALLING TO MARS 158
XVI. THE CANALS OF MARS 162
XVII. MARS—THINGS KNOWN AND SURMISED 167
INDEX 173

MARS

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MARS

CHAPTER I

FACTS ABOUT MARS[1]

Mars is to many persons the most interesting body in the heavens, chiefly because it exhibits phenomena that we cannot explain unless we assume that life in some form or other exists there.

Before describing the more recent observations of Mars, it is well to mention a few astronomical facts about the planet that are more or less familiar. Mars revolves in an orbit outside that of the earth in a period a little short of two years, and we overtake it on an average once in every two years and fifty days. I say on an average, because the orbit of Mars is very eccentric, and the time we need in order to catch up with it varies appreciably; it is longer when we overtake it in August than when we do so in February. The date on which we overtake and pass it is called the date of opposition, because the planet is then just opposite the sun, and rises at sunset. In August, when Mars is nearest the sun, we approach to within 35,000,000 miles of it, but at a February opposition we do not get nearer than 62,000,000 miles. The day of Mars is about forty minutes longer than ours, and the inclination of its axis to its orbit virtually the same as ours, 23.5°.

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[1] Youth's Companion, 1917, **91**, 639.

PECULIARITIES OF THE PLANET

The diameter of Mars is 4230 miles—only a little more than half that of the earth; and the force of gravity on its surface is about two-fifths as great as that on the surface of the earth. That fact is of the greatest importance to the life on Mars, for because of it the atmospheric pressure on its surface is probably not much more than one-tenth of our own. The boiling point of water on Mars, therefore, is only about 115°; if Mars were as warm as the earth, water would boil when merely exposed to the sun.

Snow melts at the same temperature on Mars that it does on the earth, namely 32°. When the north pole of Mars is turned toward the sun, the huge snow fields that surround it melt rapidly, and large dark areas, which sometimes cover two million square miles, form round them. These are undoubtedly marshes.

At times certain parts of the marshes become dark blue in color, and we believe therefore that those parts are lakes. Although they are usually confined to the regions that surround the polar snowcaps, they sometimes appear in other parts of the planet. None of them are permanent, however; the blue color seldom lasts more than a few weeks. We suppose, therefore, that they are shallow, and that the water evaporates rapidly under the low atmospheric pressure.

Often great indistinct yellowish-white bodies rise from the marshes and, as the planet revolves on its axis, follow them across the face of the disk. We can hardly doubt that these objects are clouds and fog.

When the polar caps are melting, the atmosphere of Mars contains as much water vapor as our own, but much less of the permanent gases. Because of that, and of the low temperature of the boiling point, evaporation and condensation occur much more rapidly on Mars than on the earth. As a result their atmosphere at sunrise and sunset is full of cloud, which probably lasts all night. These cloudy nights help to keep the planet warm, and the clear days also tend to warm it up. Except near the equator, however, the climate on Mars must be subject to great extremes of temperature, and its nights are without much doubt bitterly cold. Of one thing we can be quite sure: to beings constituted like ourselves the climate there would be very disagreeable.

The surface of Mars may be roughly divided into two parts—the dark areas and the bright ones. The dark areas were formerly supposed to be seas and the bright areas continents, but now we know that that is not the case, and that there are no permanent seas on Mars. What seems more likely is that the regions that are permanently dark are areas covered with vegetation; that those that are temporarily dark are marshes; and that the bright regions are deserts. Crossing both the dark and the bright regions we find a network of canals—perhaps not so many as are shown by some observers, but certainly a large number. At the junction of the canals with one another, and with the seas, we often find little dark spots, which we call lakes.

Of course we do not call them canals and lakes in the terrestrial sense of the words. Those are merely names, just as we call dark markings on the planet seas. We do not know yet what the canals and lakes really are, but of one thing we are fairly certain, and that is that they are not water. Probably, like the seas, they are strips covered with vegetation. Of course there may be some water in them. The polar seas are really marshes, and the same may be true of the ephemeral canals—those that are short-lived and that soon dry up.

Some observers believe that each canal contains a central ditch or pipe by which the canal is irrigated, and that what we see is the vegetation growing in that irrigated region. They believe that the main object of the canals is to conduct water from the polar caps to the great so-called seas, situated in the southern hemisphere of the planet, and that huge engines pump the water through those pipes or ditches. One writer has even gone so far as to compute what horse power would be necessary to accomplish that task, and finds that it would require about four thousand times the amount of power that Niagara gives.

THE SHIFTING MARSHES

All these conjectures seem to other observers most improbable. If the snow at one pole of the planet is exposed to continuous sunlight, under which it melts rapidly, it adds a great deal of water vapor to the atmosphere, and so increases the pressure; if the other pole is exposed continuously to the terrible cold of interplanetary space, it has scarcely any atmosphere to protect it. We cannot doubt therefore that strong atmospheric currents must pass from the sunlit pole to the other, bearing the water vapor with them. In fact, we know that that is the case, for we can see that the snow is transferred from pole to pole and back again every year by a process of distillation and condensation.

Indeed it seems to me that the hard thing to understand is, not how the water may be transported across the planet, but rather how it may be kept from going too fast and leaving the intermediate surface a waterless desert for a large part of every half year. If the so-called canals have some function to perform in the tremendous transportation scheme on Mars, it is surely not that of conduits but rather that of reservoirs to hold back the flow. For, with the low atmospheric pressure on the planet, the evaporation from every liquid or moist surface must be intense.

If a current of air bearing moisture sets south from a certain point, let us say a large marsh near the north pole, it will not long retain that direction. When it starts it is moving not only south over the surface but also toward the east with the surface of the planet, as it revolves on its axis. As the current of air gets farther and farther away from the pole, the underlying surface travels faster and faster; thus the air current that it leaves behind seems to blow toward the west as well as toward the south; that is, it seems to come from the northeast. We are quite familiar with this phenomenon on the earth, under the name of the trade winds.

When the sun rises on such a polar marsh or lake, the water at once begins to evaporate. It does not generally form a cloud, however, but remains a transparent volume of vapor or gas, moving slowly southward. When night falls it condenses to a cloud, and much of it remains in that condition until the following morning, when we see it following the marsh, and sometimes at one or two hundred miles distant from it. The part of the cloud that does not remain in that condition through the night must be precipitated on the surface as snow. When the sun again rises on it, it will melt, and thus moisten the western or following side of the marsh, while the eastern side gradually dries up. If the surface of Mars is very level, as we believe to be the case, and if our reasoning is correct, those marshes should then be found to shift their positions slowly, and to travel southward and westward.

Now, that is exactly what has been seen to take place. In December, 1913, an observer drew a map to show the marshy region that formed a part of the great marsh surrounding the polar snowcap of Mars. In the following January he again observed that region, and made another map. Much to his surprise, he found that the two maps did not agree—that the marshes had shifted slightly toward the west. At first he thought he had made a mistake, but after a little thought he found the explanation. Since then other polar marshes have been observed, and the same shift has been seen.

The fact that the polar canals also shift at times with the retreat of the snowcap is one of the reasons why we believe that some of the canals are merely marshes. Certain other canals sometimes shift, however, and for no apparent reason, and in no predictable direction. The same is true of the southern permanent seas. The canals are so narrow that we cannot tell what their color is, but the seas turn from gray to green when the moisture from the polar caps first reaches them; the color is at times very vivid, so that we feel fairly confident that the seas at least are areas of vegetation.

If on the earth an area of the size of our New England States should within thirty years change from a fertile plain to a barren desert, we should consider it as a real catastrophe. It is because apparent changes of that character do occasionally occur upon Mars, and because similar temporary changes occur frequently, that astronomers find the planet of so much interest.

The temporary changes are most frequent at the time of the development of the dark regions, which occurs when the polar caps are melting most rapidly; but astronomers have only begun to study them within the past few years. Since no single observer can keep all parts of the planet under constant inspection, an association of observers interested in Mars has been formed. These observers are stationed in the United States, in Japan, in Australia, in Asia, in Italy, Denmark, France, and Great Britain. They send in regular reports to a central bureau, which publishes the results in one of the astronomical magazines, whence they are distributed to astronomers throughout the world.

It is easy to measure the length of the canals, and also the breadth of the wider ones, but to measure the breadth of the narrower ones is more difficult. There are many canals from one thousand to two thousand and even three thousand miles long. When they first appear they are often more than two hundred miles, broad, but as the season progresses they narrow, and new and much smaller canals appear. We have measured some of these smaller canals, and believe that some of them are less than ten miles wide. The larger lakes situated at the junctions of the canals are sometimes several hundred miles in diameter, but the smallest ones that we can observe are probably no more than fifty.

As compared with our earth, it is certain that Mars has a scanty supply of several substances needed to support life. One of them is water; the Martian supply of that is certainly less than one one-thousandth of what we have upon the earth. Of course it is true that we have a great deal more water than we need. Another necessary is nitrogen, which is needed for plant food. We have at least forty times as much of it for each square mile of land surface as is found upon Mars. Another very important plant food is the gas, carbon dioxide, that our terrestrial volcanoes supply to our vegetation. If that supply should be cut off, our vegetation would soon die, and that would be the end of all animal life upon our planet. Mars is a world more ancient than our own, and it is quite possible that there is little volcanic activity there at present. If so, carbon dioxide must be in great demand.

CHAPTER II

PHOTOGRAPHS OF A SNOW STORM ON MARS[1]

A box of negatives has recently been received from the temporary Harvard observing station upon Mt. Wilson, California, and contains among other things a number of plates of the planet Mars. Seven views were taken April 9, between 22h. 56m. and 23h. 41m., Greenwich mean time. Seven more were taken April 10, between 23h. 20m. and 23h. 32m. Thus the same face of the planet was presented in both cases. Distinct and identifiable spots and markings are well shown in all the pictures, but in those taken on the latter date a considerable accession is shown to the white spot surrounding the south pole. It has been known for years that the size of these polar spots varied gradually from time to time, apparently diminishing in the summer, and increasing in the winter of their respective hemispheres. But I believe that this is the first time that the precise date, and approximate extent of one of these accessions has been observed. The area affected stretches from the terminator, which at this time was in long. 70°, along parallel — 30° to longitude 110°, thence to longitude 145°, latitude —45°; thence to the limb which was in latitude —85° and the 220° meridian, and thence back to the point of starting. It may thus extend also over an unknown area on what was at that time the invisible hemisphere of the planet. The visible area included is surprisingly large, amounting to about 2,500,000 square miles or somewhat less than the area of the United States. Being near the limb, however, it is not as conspicuous as might at first sight be supposed. On the morning of April 9, the area was faintly marked out as if pervaded by haze, or by small separated bodies, too small and too far apart, or too faint to be recognized individually. But on April 10 the whole region was brilliant, fully equaling that surrounding the north pole. In the meantime a much smaller area on the limb which on the 9th was very bright had either vanished or joined the main mass, by moving eastwardly, as we should say, considering Mars as a globe.

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[1] **Sidereal Messenger, 1890, 9, 254.**

The date of these events corresponds to the end of the winter season on the southern hemisphere of Mars, or what would be with us about the middle of February. The numerical data given above are founded on the extremely useful tables published by Mr. Marth in the *Monthly Notices*.

As to what these observations mean, might most naturally be explained by terrestrial analogies, but be that as it may, the facts are that these appearances are conspicuous upon each of the fourteen photographs, and so distinctly so, that no one who had once seen them would hesitate an instant in deciding on which day any particular plate was taken.

CHAPTER III

THE GLACIAL PERIOD AND THE PLANET MARS[1]

It seems to me that one of the chief secondary causes of the Glacial Period, as based on an increased eccentricity of the Earth's orbit, has not heretofore been sufficiently enforced. During the short winters and long summers, whatever precipitation occurs will be largely in the form of rain. On the other hand, during the long winters and short summers it will be, on the whole, mainly in the form of snow. Now the snow by its great reflective power will cause the earth to lose a very large proportion, perhaps nearly three-quarters, of whatever radiant energy does fall upon it. Moreover, during the short summer, when the sun is able to melt the snow, there will be an extensive evaporation from its whole surface, forming clouds. These will in their turn reflect away the sun's rays, and at the same time by their shade protect the snow beneath them from melting.

This cause requires for its action the presence of considerable moisture upon the surface of the planet. It has been stated that the glacial theory does not appear to apply to Mars. In the case of this planet, however, we have good reason for thinking that it formerly had extensive oceans upon its surface, and the gradual cooling to which it has been subjected has enabled room to be formed for them in its interior; that is to say, there are probably extensive regions in its interior which are not sufficiently hot to convert water into steam. The water would therefore, naturally, as is the case with the earth, go underground, filling all the microscopic cavities between the rocks. Be that as it may, the appearance of the surface of this planet leads us to think that it possesses at present very much less water in proportion than does our earth. That being the case, there could not be sufficient evaporation to form the extensive snow-caps required by the glacial theory. As an illustration of this point, we should expect that the northern or continental slopes of the Himalaya Mountains would be colder but also drier than the southern ones, which are exposed to the ocean. Yet upon the warm southern slopes we find the line of perpetual snow considerably lower than upon the colder northern ones. Thus, because the supposed snow-caps upon Mars are small, it does not necessarily indicate that the temperature of the planet is higher than that of the earth.

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[1] Knowledge, 1892, 113.

CHAPTER IV

COLORS EXHIBITED BY THE PLANET MARS[1]

The following preliminary account of an investigation made in Cambridge at the last opposition of Mars, is published at this time, in the hope that others may take advantage of the present favorable circumstances, to verify the results here described. One of the most difficult branches in practical astronomy is that pertaining to the colors of the heavenly bodies, for no other optical illusions can be found to be so complete as those pertaining to color. The planet Mars is frequently spoken of as the red planet, yet its color is by no means as red as that of an ordinary candle flame. To illustrate this fact, let the observer so place himself that the planet Mars, an electric light, and a candle or gas flame, all appear to him to be of the same brilliancy. He will then find that while the planet is redder than the electric light, it is bluer than the candle flame, and is, in fact, very nearly half way between the two in color. If either source of light is made brighter than the other, its tendency is to appear whiter.

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[1] Astronomy and Astro-Physics, 1892, **11**, 449.

During the last opposition, sixty paintings were made of the planet, with the 12-inch Harvard refractor, and sixty-six uncolored drawings. They were all constructed upon a uniform scale of $\frac{1}{200,000,000}$, the planet being represented by a disc, 34 millimeters in diameter. Usually powers of 200 to 400 were employed. It was found that in the evening, the most prominent and striking color of the planet could be represented very well by carmine. It was also found that it could be equally well represented by golden yellow. When painted in the day-time it was orange, with more or less carmine, depending on various circumstances. If a high power was used it was much redder than with a low power. All of these changes may be readily explained by the elementary principles of physics, but they illustrate very well some of the difficulties that were presented by the research. As the planet is illuminated by sunlight, it is evident that in order to obtain a correct result, the pigment used to represent it should be illuminated by the same source. The paintings should, therefore, be made in the daytime.

Experiments were also made in a darkened room, the only light transmitted being through a small round hole bored in the shutter. Various pieces of colored stone were placed upon a mirror, which reflected the light of the sky into the room. Reflections of these stones were then viewed in two pieces of flat glass, supported inside the room. By varying the angles of the glasses, the intensity of the sunlight reflected from the stones could be varied, so as to render them either brighter or fainter than the planet, as seen in the telescope. Paintings of the planet, illuminated by the same light as that used in the evening, were then compared with the light from the stones.

The other shutters of the room were then opened, and the paintings illuminated by daylight. It was found that the same laws of color held good with the stones that had been previously found applicable to the planet. The various stones tried were a piece of brown lava from Vesuvius, a piece of red basalt, a piece of brown sandstone, a piece of very red granite, and two pieces of brick, one an orange red, and the other the color of dragon's blood. The former may be best represented by dragon's blood with a little Saturn red in it. The red granite, which is half way in color between the two pieces of brick, is well represented by dragon's blood and sienna, half and half. It was found that this piece of granite under suitable illumination could be made to match exactly any of the paintings of the planet. As its color was not far from that of an average brick, our next experiment was to select a distant building made of brick of the proper color, and make a painting of it as seen in the telescope. This painting was necessarily made by daylight, and another telescope had to be used, as the building was not visible from the dome of the 12-inch. The building selected was two and a half miles distant. The telescope employed was a 6-inch refractor by Clacey. The result was as anticipated, that when the painting of the building was compared with some of the daylight paintings of Mars, the colors were identical. In each case the colors were separately mixed at the time, although the components were the same, and in each case the result exactly satisfied the eye.

The reason that a red planet or distant brick building can be matched by daylight with an orange pigment is because of the bluish white light reflected from the atmosphere, lying between the distant object and the eye, which is mixed with the red light coming from the object, changing it from red to orange. If the brick is examined close at hand, a red pigment must be employed to represent it. When the planet is viewed at night, or when a piece of brick near at hand is illuminated by sunlight, but the pigment is illuminated by a yellow artificial light, this light by enforcing the red components of the pigment, and absorbing the blue, makes the pigment really appear red, and therefore match the Sun-illumined object. The object, therefore, although painted yellow by night, really appears to the eye redder than when painted orange by daylight. This fact was well brought out by an experiment made at night, employing the magnesium light instead of the oil lamp as a source of illumination for the pigment. In that case the color best matching the planet was found to be dragon's blood which, as we have seen before, is probably not far from its true color, which we considered to be the same as the red granite, and therefore to be represented by equal parts of dragon's blood and sienna.

But red is by no means the only color visible upon the planet. When near the limb, the reds always appear yellowish, indicating probably an atmospheric absorption of the red portion of the spectrum, an effect quite at variance with the action of our own atmosphere, which tends to absorb the blue rays.

Next to the reds and yellows, the most important colors are the grays and greens. The latter colors one would actually at first attribute to an optical illusion, due to contrast with the prevailing tint. If this were the case, however, these portions of the planet should be painted blue, blue being the complementary color of the orange seen by daylight. Blue pigment seen by lamp light becomes green, which is the complementary of the red seen at night.

Therefore in either case blue would be the complementary color and not green. Experiments under both of these conditions, however, made upon several occasions, conclusively showed that these greens could not be matched by blue pigment of any tint, but were a true and genuine green. Although rare, yet upon four occasions it was noted that green was the most conspicuous color visible. This was due sometimes to its covering a large area, and sometimes to its being a more intense color than the red. This also indicated that the green could not be due to contrast. It was found by experiment that the effect upon green pigment produced by using an artificial illumination was very much less marked than upon red, the only effect being, that when so illuminated, it appeared rather more yellow than when seen by daylight. This would imply that the greens upon Mars were in reality slightly more yellowish than the evening paintings would indicate.

When the seeing became bad the greens and reds united to give a whitish tint, and the colors disappeared. This further indicated that the greens were not due to contrast. A piece of black paper was introduced into the field of view of the telescope, cutting off the red, but the green color remained unchanged. An examination was made of Jupiter, the disc being a bright yellow, but no green could be detected upon it. The greens, especially the light greens, usually appeared near the poles, which were necessarily near the edge of the disc, but on these occasions a region near the center was seen of a light green color. The green could not therefore be attributed to the secondary spectrum of the glass. Moreover, the telescope was thrown alternately slightly in and out of focus, changing the color of the outside fringe of light, but without altering the green hue upon the disc.

The green was not due to atmospheric refraction since it was seen near both poles, besides which the color due to this cause is easily overbalanced by that due to the lack of achromatism in the eyepiece when the planet is placed near the edge of the field. The green is not due to an optical illusion caused by the brightness of the snow. It is sometimes seen between the snow and the red regions of the planet, and is also seen when the snow is not visible. Indeed I think it has been often mistaken for the snow, as it is a much larger and more conspicuous object. The real snow is much more difficult to see than is generally supposed, and is frequently not visible at all. I have only seen it occasionally when it was readily distinguished by its extreme brightness and whiteness. An excellent idea of its appearance is given in Chambers' Astronomy, fourth edition, and I have seldom seen it of much greater extent. The drawing is by Green, and like all of his work upon Mars, is most accurate and life-like. The gray objects upon Mars, when the seeing was poor, acquired a slightly yellowish, and in the day-time a brownish tint, owing to their confusion with the surrounding regions, but when the seeing was good, they were either a pure gray, or of a slightly greenish color. This does not apply to all the darker regions, as we shall see later. There was no difficulty in obtaining distant green terrestrial objects to study through the telescope, and it was found that even upon very clear days, when over two or three miles distant, they appeared either gray or greenish gray. This was particularly true of the darker shades. In fact I never at any time saw any colors as brilliant as the bright greens upon Mars. Even when a piece of bright red paper was introduced into the field of the telescope, no appreciable contrast effect was produced upon the terrestrial greens. This fact, together with the other that the greens on Mars were seldom seen by daylight, made me think that those seen upon the planet must be due to some illusion, whose origin had not as yet been eliminated, for one cannot well conceive of more vivid greens than those due to some of our own vegetation. I had been observing a tree some two and a half miles distant with the telescope one very clear morning, when I noticed that there was an electric lamp just by the side of it. That evening I pointed the telescope again on the tree, and it instantly shone out a most brilliant bluish green, fully equalling in intensity anything I had seen upon the planet, and a trifle bluer. This explained why it was that in the day-time I had only detected the greens upon Mars with difficulty while at night they were conspicuously visible,—the white light reflected by our own atmosphere had corrected them into grays.

Numerous observations were made of the colors of particular regions, especially of those which appeared very dark in tint. Attempts were also made to determine the color of the canals. This latter is an extremely difficult undertaking, as the smaller the area, the harder it is to assign any particular color to it. The apparent area of any very small region always strongly affects one's judgment of its color, and in comparing two colors, it is most important that their apparent areas should be equal. Regarding the colors of these smaller regions, as it is very desirable that the opinions of others be formed independently of my own, I will defer describing them until another paper, merely stating that there is some evidence that certain regions do not seem to remain at all times of the same color.

In closing, I shall mention that these colors have been seen through three different telescopes, 12-inch and 15-inch at Cambridge, and more recently through the 13-inch instrument at Arequipa. The latter instrument brought them out very finely, the greens showing well even in the day-time. On April 5, I could see the great canal north of the Syrtis Major with a power of 810 diameters. It will be noted that in what precedes I have carefully abstained from advocating any hypothesis regarding the true sources of any of the colors, merely confining myself strictly to a statement of the observed facts.

In my former paper upon this subject, attention was called to the important effect of our own atmosphere in misleading our judgment as to the true colors exhibited by the heavenly bodies. A good illustration of this effect may be obtained from a mountain summit upon a slightly cloudy day. The distant greens of the landscape, which are by no means as brilliant as when viewed close at hand, are at once changed to grays either by the passing over them of a cloud shadow, or by the passing of a very thin mist between them and the eye. In the former they become darker, and in the latter lighter, but in either case the greenish tint entirely disappears.

The sudden changes of color exhibited by some of the smaller areas upon the planet Mars are sometimes almost startling. A recent view was obtained shortly before sunrise, when the snowy region about the south pole appeared of a most brilliant green, quite equalling in color the rather narrow green band situated just to the north of it. Later as the

Sun came up, the color of the snow changed to bright yellow, the rest of the disc changing in the mean time to orange. Later the seeing improved, several of the canals became visible, and the snow became as colorless as that upon our surrounding mountains. The two former effects were probably due to bad seeing, the fluctuations of our own atmosphere superposing the colors of the surrounding regions upon the snow. We have laid it down as a rule never to rely greatly upon our color observations unless the snow caps of the planet appear perfectly colorless, and the canal system is well defined. These conditions we find always combined with the best seeing. For these delicate color observations it will therefore be seen, that not only do we require a telescope of the very first quality, but also the very best obtainable atmospheric conditions.

In studying the smaller dark regions, such as the northwestern part of the Syrtis Major, great differences of color have been noted from night to night, and I have colored sketches in my possession, taken at different times, in which it is represented as grey, as green, as blue, as brown and even as violet. The latter color was so extraordinary that I endeavored to make that portion of the planet appear to my eye of some other color, but it was impossible, and no other color but violet lake could be made to match it. This color upon the planet has only been seen by me upon one occasion since. The brown color above noted was undoubtedly due to bad seeing. At one time I felt convinced that the real color of the darkest spots upon the planet was a deep blue, and this may in reality be the case, but of late, under the most favorable circumstances, they have appeared to me of an absolutely colorless dark grey. Probably this point can be settled at the present opposition.

Before describing the colors of particular regions more at length, it may be well to give a description of the general characteristics of different longitudes, as observed during the opposition of 1890. For this purpose we may divide the surface of the planet into six sections, each sixty degrees of longitude in breadth, the first having the 0° meridian central. The times of transit of the 0° meridian of the planet may be readily computed, but the amateur will find them given in convenient shape in the excellent ephemerides published by Mr. Marth in the *Monthly Notices*. The only pity is that these ephemerides cannot appear about six months earlier, in order to be of the most use to astronomers outside of the British Islands.

The most striking marking upon the planet, and that most readily seen with a small telescope, is the Syrtis Major, or Y mark. This is nearly central in the sixth position of the planet, with the 300°

meridian in the middle of the disc. Owing to the period of rotation of Mars being 37 minutes longer than that of the Earth, in about six nights Mars will be found at the same hour in the fifth position with the 240° meridian central. This region in 1890 was interesting as containing the most conspicuous canals visible upon the planet, excepting the large one which terminates the Syrtis Major upon the north. At this opposition these canals will all be too far north to be well seen. The fourth and third regions of the planet were both extremely uninteresting as showing very little detail of consequence. The second position with the 60° meridian central was interesting as showing the great southern ocean, which is nearly as conspicuous as the Syrtis Major itself. In the first position with the 0° meridian central the ocean is disappearing and the Syrtis Major coming into view.

We now come to a curious feature of the observations, namely, the actual changes in color which, eliminating all probable sources of error, the surface of the planet really seems to undergo. When the Syrtis Major is central, before the autumnal equinox of the northern hemisphere, the region to the east is seen to be distinctly more greenish than that to the west. As the season wears on the difference in color becomes less marked, and the greenish hue is confined more closely to the region immediately bordering the Syrtis on the east. In most of my drawings made in 1890 the two arms of the Syrtis are shown of equal breadth. This appears to be the case also upon Green's map published in Chambers' Astronomy, although this point is not well shown by him. At present there is no doubt but that the eastern arm is much the wider of the two, perhaps twice as wide. Early in 1890 the entire region enclosed between the arms of the Syrtis Major, as far as the snow cap, was of a brilliant green color. On June 27, however, or eleven days before the vernal equinox of the southern hemisphere, a yellow spot appeared at the extreme northern point of the triangular area. As the season advanced this yellow spot increased in area, till it covered the whole region as far south as could be seen. This year when first observed, this area was entirely green, but on May 9, or seventeen days before the vernal equinox, the yellow or perhaps reddish spot appeared in the same place, and it will be interesting to determine if, as the season advances, this color again progresses towards the pole. Changes to the east of the Syrtis Major have also been noticed by Schiaparelli. These he ascribes to extensive floods. On June 8, 1890, thirty days before the autumnal equinox in the northern hemisphere, there was a large greenish area visible in longitude 180°, latitude 30° north. By July 16, or eight days after the equinox, this spot could not be found, the whole region appearing of a yellow tint. In longitude 10°, latitude 40° north, is a large crescent-shaped area. In June and July, 1890, it was well seen and appeared quite as dark as the great southern ocean. This was noted upon a number of occasions. It was however painted green, and the ocean to the south of it blue, the difference in color on one evening being very clear, as seen by my assistant, Mr. A. E. Douglass, and myself. On March 22 of the present year the crescent was well shown, but was markedly fainter than the ocean, which was again suspected of being blue, but the color could not be satisfactorily confirmed. This crescent is now too far north, owing to the motion of the planet, to be satisfactorily studied.

While these indications of change of color upon the planet are too few and isolated at present to enable us to form a satisfactory explanation of their causes, they still hold out a promise that should these observations be carefully repeated at future oppositions, under suitable conditions, we may in time be able to deduce the laws affecting them, and perhaps even predict their changes in advance. Too much stress however cannot be laid on the danger of optical illusion in this matter. It is generally considered that a very good instrument, and some practice is required, before an observer can certainly see the canals even, but in order that satisfactory results in this branch of the research may be achieved, the more important canals must be seen with distinctness, and the snow caps, if present, must appear perfectly colorless.

CHAPTER V

CHANGES AND FLOODS ON MARS[1]

In the previous chapter an endeavor was made to show that actual changes do occur upon its surface, besides the well known annual change in the size of the snow caps. This effort has perhaps proved unnecessary since the changes which have actually occurred at the present opposition have been so conspicuous and startling that they might easily be detected even by the possessors of six-inch telescopes. The canals can now be observed readily any evening. Many of those that we have seen here agree with Schiaparelli's, and several do not. Several of his more strongly marked ones have not been found at all. This, however, I am quite prepared to attribute to seasonal changes. Some very well developed canals cross the oceans. If these are really water canals and water oceans, there would seem to be some incongruity here. When the snow melts, it seems that there really should be some oceans, and a careful study has been made of the dark spot previously referred to, at the northern end of the Syrtis Major. Although sometimes dark gray, yet in the great majority of cases when the seeing is satisfactory, and the spot is central, it appears of a clearly defined dark blue color. Another spot presenting a precisely similar appearance occupies a portion of the Sinus Sabaeus or Herschel Strait.

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[1] Astronomy and Astro-Physics, 1892, **11**, 668.

These two spots when near the limb have on several occasions been observed to be of a beautiful bright blue color. If they are really oceans, they must, under these circumstances, be reflecting to our eyes the color of the Arean atmosphere, as water would, under similar conditions, do upon our Earth.

Viewed with a double image prism these spots when near the limb seem to present faint traces of polarization, the plane being radial to the planet. Until very recently they were much darker than any other spots visible, although a dark region near Solis Lacus (Terby Sea) has upon one occasion appeared quite black. It is my impression that these two areas are really water, and in the present article they will be referred to provisionally as the Northern and Equatorial Seas respectively. As I have stated in former articles I very much doubt if what are usually known as oceans and canals contain any water at all. That is to say, any water which is visible as such, for it is quite possible and perhaps probable that they may owe this color indirectly to the presence of water, stationary or running.

The boundaries of the Equatorial Sea (Fig. 2) are all sharply defined. It is 1,300 miles in length, east and west, and averages a trifle over 200 miles in breadth, with two deep bays slightly curved, and almost precisely alike, opening southward, at its western end. In this article I have adopted the precedent set by Professor Schiaparelli in applying the terms east and west with the same signification as is given to them in maps of the Earth. That is they are reversed as compared with other celestial maps. Its total area is 275,000 square miles. The shape of the Northern Sea (Fig. 3) is that of an irregular quadrilateral, 750 miles in length by 600 in breadth. On the north its outlines are as clearly defined as those of the other sea, but on the south it is bounded by a dark gray region, never seen hitherto to be blue and which I am inclined to ascribe for reasons which will appear later to low land. If its shores were indented, this might account for their rather indistinct appearance. Its area is nearly equal to that of the Equatorial Sea, being approximately 225,000 square miles. What we may therefore speak of as the permanent water area upon Mars amounts to about half a million square miles. This is exactly one-half the area of the Mediterranean Sea. A glance at the map of the world in two hemispheres will give the reader an idea of the enormous disparity in the water area of the two planets. From this circumstance we might expect the climate of the smaller planet to be on the whole much the dryer of the two, and if all is not a desert, at least that the deserts would be much more prominent than upon the Earth.

In this connection we may refer to the green areas situated near the poles, and described at some considerable length in the previous chapter. It was there stated that after the vernal equinox the greens almost entirely disappeared and the question was raised whether the same effect would be noticed this year. We can now reply in the affirmative, for although we have searched for them with the utmost care of late, when the seeing was both better and worse than before, scarcely a trace of them have we been able to detect. There is also a green area to the west of the Equatorial Ocean, but this region we have not been able to inspect carefully of late. In case they should reappear before the present opposition is over, as is possible, it is hoped that others will be upon the watch to detect them, and accurately locate their positions. While their reappearance might with some show of probability be attributed to the presence of one of the great branches of organic life upon the planet, and with this branch, as an almost necessary corollary, the other one, we must still consider the matter merely in the light of a tentative hypothesis, until further observations are accumulated, and content ourselves with the statement that no facts have as yet been observed inimical to this idea. The one fact which we have so far attempted to demonstrate is the presence upon the planet of water in the liquid form, and the attempt has been made to determine its exact location, and the area and shape of the surfaces permanently covered by it.

As might have been expected from the position of the planet's axis, the snow cap is much more conspicuous at this opposition than it was at the last. On June 23, the northern limit of the southern polar snow cap was, on the average, in latitude —65°. This in our northern hemisphere would correspond to the latitude of northern Siberia, Iceland, and northern British America. As this date was but thirty days after the passage of the vernal equinox, it will be seen that the line of melting snow was rather nearer the pole than we might expect to find it upon our own Earth at the same period. The area of this snow cap was some 2,400,000 square miles. Upon this date a small dark spot was noted near the center of the snow. The spot was then well developed, and must have been already existing for several days. Since that time it has grown rapidly, soon splitting the snow cap into two unequal parts, and of late changing its shape materially. The snow cap in the meantime has rapidly diminished in size, so rapidly in fact, that considering the weakened power of the sunlight at that distance, we are forced to believe that its depth is much less than that of the similar deposit covering the poles of our Earth. It will thus be seen that the comparatively small snow caps of Mars by no means necessarily imply a warmer climate than that of the Earth, as some writers have assumed, but merely a drier one. If the snow fell to a less depth, a larger proportion of the heat absorbed in the higher latitudes could be employed in raising the temperature, and a less amount absorbed in the latent form. This would involve a somewhat higher temperature during the summer, but a longer period of intense cold during the winter, than exists upon the Earth, in proportion to the length of the year.

Upon July 26 it was found that the area of the snow cap had diminished to 800,000 square miles. An area of 1,600,000 square miles of snow had, therefore, been converted into water, in the space of thirty-three days. With our extensive oceans this would produce no material change upon the Earth, but what must be the effect upon Mars, whose total permanent water area amounts to less than one-third of this figure? Moreover, upon the Earth the semi-annual transfer of the melted snow from pole to pole is conducted by means of the oceans, but upon Mars this transfer must take place across the land. We should naturally expect that a considerable proportion of the water would be absorbed or deposited upon the way. It will therefore be interesting to notice what has actually been observed.

Eastward of the stem of the Y*, in what is known as Libya, there was observed by Mr. A. E. Douglass upon May 8, and by myself quite independently, upon May 9, a light colored triangular region with a bright triangular center (Fig. 1). The angles of the central region were so distinct that they were selected as stations for our micrometric survey of the surface. At the next presentation of this phase, a month later, the central triangle had entirely vanished, being of the same tint as the outer triangular area, thus rendering it quite impossible to employ the selected stations. The whole area was, however, still much lighter than the stem of the Y. June 11, it had a decidedly greenish gray tint when central, and two days later it had assumed the same gray color as the stem of the Y from which it was indistinguishable. July 17, that portion of this region south-east of the Northern Sea had become extremely dark (Fig. 4), being only exceeded in tint by the sea itself, which differed from it mainly in color, the sea being blue and this region gray.

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* The Syrtis Major.

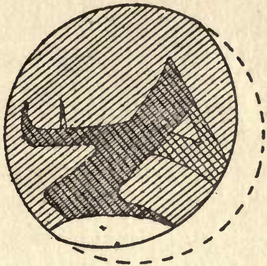

Fig. 1
May 9, 21^{h} 05m

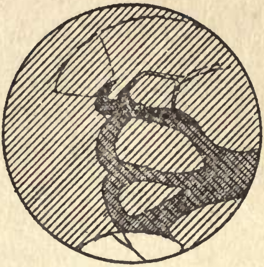

Fig. 2
July 14, 16^{h} 50m

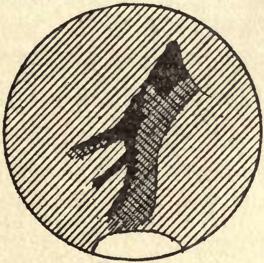

Fig. 3
July 16, 17^{h} 45m

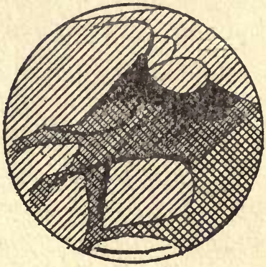

Fig. 4
July 17, 15^{h} 50m

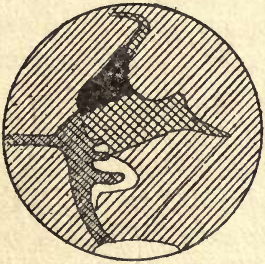

Fig. 5
July 23, 17^{h} 30m

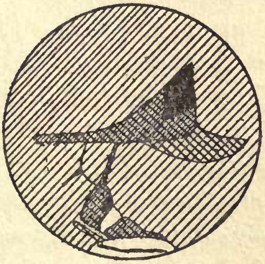

Fig. 6
July 25, 20^{h} 40m

Note in Regard to the Figures. In the above figures north is placed at the top. The date is given in Greenwich Mean Time. The scale is 200 kilometers (125 miles) to the millimeter. In the last five figures 1″ = 1.4 millimeters.

Upon July 10, the region south-west of the Equatorial Sea was extremely faint, and but little darker than the reddish region to the north of it. A similar effect had been suspected in June. This seems the more singular, since after the Seas this is usually one of the very darkest and most conspicuous markings upon the planet. The region west of this has also been subject to various changes, which need not, however, be described in the present article.

Upon May 12, it was noticed that the southern snow cap was bounded by a very fine black line. By June 23 this had become quite conspicuous in some places. By July 10, that portion of the line lying upon the Arean meridian was as dark as the Equatorial Sea, and appeared quite like it. On July 16, a small elongated black spot was noticed upon the western side of the stem of the Y (Fig. 3). It was then so conspicuous, that I was surprised I had not noticed it before. My measurements indicated that it was about 125 miles in length by 75 miles in breadth. This would make it of about the same size as Lake Erie, and it was connected with the Northern Sea by a very narrow straight black line. This line did not at all resemble the so-called canals, being much finer and blacker. This spot was again seen by myself upon July 17, and by Mr. Douglass upon July 22, after which it disappeared unexpectedly in a way which I shall presently relate.

Changes were now coming thick and fast upon the planet, and when evening came round, and we put our eyes to the telescope, we never knew what we should see next. In my August paper reference is made among other suspected changes to the two arms of the Y, which in the opposition of 1890 were always drawn of approximately equal width. The statement was then made: "At present there is no doubt but that the eastern arm is much the wider of the two, perhaps twice as wide." This paper was completed May 13, 1892. This statement still remained true upon June 10 and 11, but at the next presentation upon July 12, a central arm was shown, converting the Y into a trident. This arm connected directly with the dark streak or split in the snow cap (Fig. 2). The eastern arm was still much the widest, but in two days the difference between it and the western was much less marked, and by July 17, they were equal in breadth, just as they appeared in 1890 (Fig. 4). In the meantime the central arm of the trident had become much more prominent, being about equally conspicuous with the other two, and now, to my astonishment was seen a large dark area south-east of the Northern Sea and of fully double its area. This dark region is the one referred to earlier in this paper as having formerly been very light colored. It was now nearly as dark as the Sea, and much darker than that part of the

Y to the south of it. In color it was gray, and not blue. This observation was independently confirmed by Mr. Douglass the next evening. By July 23, this darkening had greatly diminished, the color of the dark region being of the same depth as that of the rest of the Y (Fig. 5), which latter had now materially changed its shape, owing to eastward extensions of the eastern arm. In the meantime the central arm, recently so strongly marked, had completely disappeared. But what was most extraordinary was that the Northern Sea had now extended far to the south-west, completely concealing the little lake and the channel connecting the two. This result was also confirmed independently by Mr. Douglass the next evening. By "independently" I mean that he made his drawing without having seen mine, or knowing at all what I had seen. Indeed, both of us were doing so much observing at this time that we had little opportunity to compare results, and, unfortunately, did not fully appreciate the extent of the changes we were observing, and so devoted a considerable share of our attention to other matters. This will account for the apparent breaks in this record, for, with the exception of July 9, when some repairs were being made upon the telescope, continuous observations have been maintained since July 4.

To return to the observations, it is not clear from the record whether the southern extension of the Northern Sea was blue or gray. It was merely recorded and drawn "as dark as the Northern Sea." On July 24 Mr. Douglass also recorded a large southern dark spot which appeared to him as dark as the Northern Sea, but which I had not noticed upon the 23d. Upon July 25 the original outlines of the Northern Sea were again well seen (Fig. 6), the region south-west of it now being much lighter colored. The southern dark area seen by Mr. Douglass, and of which he had told me, was also noted. As a whole this area was not now as dark as the Northern Sea, but it contained a smaller spot which seemed quite as dark. There was also a narrow white channel extending northwards from the snow. The eastern arm of the Y, formerly so wide, was now reduced to a mere thread, while a trace of the central arm was again visible.

The Y is now so placed that it is only visible to the observatories to the west of us, and we shall not be able to observe it again until the middle of August. A striking difference may be noted in the arrangement of the dark channels in figures 3 and 4. In both instances they were well seen, and carefully drawn, and I do not see how the difference could be due to an error. The latter arrangement was subsequently confirmed by two other drawings. Regarding the former I find the record, "The dark parts are usually not more than 150 miles broad." I can scarcely think, however, that they could have been as broad as that.

The central branch of the Y was only noted by me upon one occasion in 1890, and that was upon May 25, when it was extremely faint. The date corresponding to July 12, 1892, in the previous opposition was August 24, 1890. At that time the Y was not visible in Cambridge. The corresponding date at the next opposition will be May 31, 1894. If the appearance of this central branch is in any way connected with the seasons upon Mars, it will be of interest for those observatories which are favorably situated at that time to look for it, since, should it then be as conspicuous a phenomenon as it has been this year, it could be readily detected by comparatively small telescopes.

In seeking to explain these observations, I would merely point out the fact that the changes occurred at a time when the snow was melting with great rapidity, that a dark channel suddenly appeared July 12, which had not been seen at the last previous observation of this region June 13, that it shortly disappeared again, and that a few days after this event the Northern Sea largely increased in area temporarily, or at least that its southern shores became much darker. I think these changes cannot be explained by Arean cloud effects. We have already observed large whitish patches upon the planet, which undergo considerable changes in shape and extent from night to night. We are now studying them carefully, although we find them rather difficult of observation. These changes we are inclined to refer to clouds, although the matter is not so simple as it might at first appear. If these effects are really due to clouds, they are quite different in character from the other changes noted above.

If the reader is inclined to be surprised at the extraordinary character of the phenomena now apparently occurring upon our sister planet, as revealed by the telescope, I can assure him that he is no more so than were the observers themselves. Nor do we insist upon any explanation of these changes, but only upon the accuracy of the observations themselves. Owing to our remote and isolated position, we know nothing at the present writing of what has been done and seen at the northern Observatories, and it is possible that when this strikes the reader's eye, it will not be as new to him as it is now to us. Nevertheless, I am inclined to think that owing to our splendid atmosphere, and southern latitude, portions of what precedes may still be new, although the larger northern telescopes will doubtless have detected all the more important changes.

CHAPTER VI

MARS IN 1892[1]

Now that the opposition of 1892 has passed into history, it may be well to give a brief summary of the observations made at Arequipa this year, preparatory to a more complete publication elsewhere. With one exception, the planet has been observed every night continuously, from July 9 until September 24, when the lens of the telescope was reversed, for photographic work, and the regular observations came to an end. Since the beginning of the year Mr. Douglass and myself have made 373 drawings of different features of the planet, thirteen of them being colored. Numerous micrometric measurements of the equatorial, polar, and phase diameters have been made. A large number of measurements of the snow, and other observations for correcting the physical ephemeris of the planet have been collected. Ninety-two stations have been located upon the planet micrometrically, many of them having been observed upon several different dates. Besides these, measurements of the clouds, and the breadths of the lakes, canals, and minor features have been obtained. Considerable data has thus been collected at this opposition for future discussion.

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[1] Astronomy and Astro-Physics, 1892, **11**, 849.

Turning now to what we may call the definite conclusions to be derived from our observations, we may say:—

I. That the polar caps are clearly distinct in appearance from the cloud formations, and are not to be confounded with them.

II. That clouds undoubtedly exist upon the planet, differing, however, in some respects from those upon the Earth, chiefly as regards their density and whiteness.

III. There are two permanently dark regions upon the planet, which under favorable circumstances appear blue, and are presumably due to water.

IV. Certain other portions of the surface of the planet are undoubtedly subject to gradual changes of color, not to be explained by clouds.

V. Excepting the two very dark regions referred to above, all of the shaded regions upon the planet have at times a greenish tint. At other times they appear absolutely colorless. Clearly marked green regions are sometimes seen near the poles.

VI. Numerous so-called canals exist upon the planet, substantially as drawn by Professor Schiaparelli. Some of them are only a few miles in breadth. No striking instances of duplication have been seen at this opposition.

VII. Through the shaded regions run certain curved branching dark lines. They are too wide for rivers, but may indicate their courses.

VIII. Scattered over the surface of the planet, chiefly on the side opposite to the two seas, we have found a large number of minute black points. They occur almost without exception at the junctions of the canals with one another, and with the shaded portions of the planet. They range from thirty to one hundred miles in diameter, and in some cases are smaller than the canals in which they are situated. Over forty of them have been discovered, and for convenience we have termed them lakes.

No repetition of the phenomena connected with the melting snow, which occurred in July has been observed. The Y mark has assumed its customary appearance, so that the narrowing of the southern branch seems to have been a temporary phenomenon, and was probably due to clouds. The central branch is now continuously visible, but its southern extremity which connected it with the snow has disappeared. The southern branch of the Y also seems to be gradually fading out.

Clouds have on several occasions been observed to project beyond the terminator, and also beyond the limb, thus confirming the observations made at the

Lick Observatory. The height of these clouds has been measured, and it appears that some of them attained an altitude of at least twenty miles,—a height considerably greater than that attained by terrestrial clouds. This is a result naturally to be expected from the small mass of the planet. No direct measures have been possible of the density of the atmosphere at the planet's surface, but indirect observations lead us to conclude that it is less than that at the surface of the Earth, but probably not as much as ten times less.

A curious feature of the observations has been the distinct flattening at the planet's poles, amounting to at least $\frac{1}{70}$. From theoretical considerations, unless we assume a rather improbable internal structure, it cannot exceed $\frac{1}{200}$, and that is approximately the figure which Professor Young derived from his measurements. Herschel made it $\frac{1}{16}$, Arago $\frac{1}{30}$, and other observers have obtained various results, in general greater than ours. The above figure must not be considered by any means final, but merely as an approximate minimum, since our computations have not as yet been completed. That the flattening at opposition was considerable was very evident. As no such conspicuous discrepancies among different observers occur in the case of the other planets, I am inclined to think that the variations may be real, and due perhaps to an equatorial cloud formation. Clouds are certainly very frequent upon the sunrise terminator, particularly towards the equator. In any case this is an interesting matter for investigation at future oppositions.

As the snow in melting receded towards the pole, there was a narrow, nearly straight region upon which it lingered longer than elsewhere. At present the snow is divided into two sections, one long and narrow, the other of irregular shape, and somewhat mottled. The appearance is such as might be produced by a mountain range and an area of irregular elevation, with a valley lying between them. It was from this supposed valley that the dark line issued in July connecting it with the Northern Sea.

Upon August 5, in the region just to the north of Solis Lacus, latitude — 20°, a small but conspicuous white spot appeared. It was conspicuous from being brighter than any other spot upon the planet save the southern snow cap, which it exactly resembled in color.

A similar but much smaller spot was also noticed further to the southwest. Both spots had disappeared by August 7, but careful measurements upon two nights, and several drawings, had already accurately located their positions. The larger of these spots measured about 60 miles in length by perhaps 40 in width, and was much brighter than any cloud that I have ever seen upon the planet. I am inclined to attribute both of these spots to snow. We have frequently seen small white points lying along the line which bounds the shaded regions upon the north. Early in August the whole northern edge of the Equatorial Sea was bounded by a narrow white line, while later a similar line bounded the Northern Sea upon the west. These lines were apparently due to cloud, and were not as bright as the spots of snow referred to above. Although nearly a thousand miles long, they could hardly have exceeded thirty miles in breadth.

Although Mars has been nearer the Earth at this past opposition than it will be again for fifteen years, I am quite inclined to believe that it will be better seen in 1894 than it has been this year. My reasons for this statement are as follows:—In the first place, its distance from the Earth will not be very much greater than it was this past year, and indeed for part of the time it will be less remote than it was when many of our most interesting observations were secured. Secondly, it will be much farther north, where the great northern telescopes can be used upon it to much greater advantage. Thirdly, following the melting of the southern snow, the Arean atmosphere was filled with clouds, and these did not clear away satisfactorily until the very end of August, or long after the opposition was over. It was only after the clouds began to clear, that the

Arean lakes, which have proved such an interesting feature of this opposition, began to show to their full advantage. Owing to the change of seasons upon Mars, little of this latter difficulty should be experienced at the next opposition, and it is thought that many lakes and other delicate features still remain undiscovered, which may reveal themselves at that time. Could the great 40-inch telescope of Southern California then be completed, undoubtedly the best views of the planet would be obtained at that point, but if it is not, the Lick telescope can certainly be used to greater advantage, and the Arequipa telescope to no less advantage, than was the case this year.

CHAPTER VII

SCHIAPARELLI'S LATEST VIEWS REGARDING MARS [1]

It is probable that the astronomer whose name is most closely linked with the planet Mars at the present time is Giovanni Schiaparelli. And yet although nearly everybody has heard of Schiaparelli's canals, very few astronomers even, outside of France and Italy, had until recently more than a very vague notion what were really his ideas in regard to them. This is due probably to the fact that he has written exclusively in Italian, a language which very few American astronomers, and I believe very few English ones, understand. To this fact chiefly I think is due the great incredulity with which his observations have been treated, at least until recently, in both of these countries. Astronomers could understand his maps, they knew therefore what he had done, but they could not understand his description of his observations, and so were incredulous regarding their accuracy. Moreover, such a mass of detail appeared upon his maps, which had not before been seen by others, that it completely masked the more striking features of the planet, thus rendering its appearance entirely different from that which it presented in the telescope under ordinary atmospheric conditions.

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[1] Astronomy and Astro-Physics, 1894, **13**, 632, 714.

But within the last few years a change has occurred. Flammarion has translated a large part of Schiaparelli's writings into French, a language with which most English-speaking astronomers are familiar, and moreover the canals have been seen by a number of astronomers whose descriptions of them in English and French could be understood, and were found to agree with those of Schiaparelli.

But errors are still frequently made by people who might be expected to know better. Thus, many people suppose that Schiaparelli was the original discoverer of canals, a claim which he never made for himself. In point of fact some of them appear upon maps of the planet published more than fifty years ago. The former English incredulity in the matter seems the more strange, since many of the canals were seen by Dawes in 1864, and by Burton and Dreyer in 1879. Schiaparelli however has discovered far more canals than anyone else, and he is also the discoverer of their gemination.

In this connection it may be that a brief chronological statement of the more important facts and discoveries relating to Mars will not be without interest. In compiling it I have been chiefly indebted to Flammarion's classic work "La Planete Mars," although other sources have also been consulted.

272 B. C. The first known observation of Mars is recorded in Ptolemy's Almagest.

1610. The phases of Mars were discovered by Galileo.

1659. The first sketch showing surface detail was made by Huyghens. He also suggested a rotation in 24 hours.

1666. Cassini determined the rotation of Mars to take place in 24 hours 40 minutes. He also observed the polar caps, and "he distinguished on the disc of Mars, near the terminator, a white spot advancing into the dark portion and representing without doubt, like those of the Moon, a roughness or irregularity of surface." This latter statement is curious, but the effect was undoubtedly due to irradiation, since his telescope was entirely inadequate to enable him to observe such a delicate phenomenon.

1777. With the exception of Huyghens, Hooke, and possibly Maraldi, no one succeeded in making recognizable sketches of the surface detail upon Mars for over a century, until Sir William Herschel took the matter up this year.

1783. Sir William Herschel detected the variation of the size of the polar snow caps with the seasons, measured the polar compression, and determined the inclination of the axis of the planet to its orbit.

1785-1802. Schroeter made an extended study of the planet. His drawings are upon the whole rather better than those of Herschel. He discovered among other things the very dark spots to which I have referred in my publications as the Northern and Equatorial Seas. He, however, supposed them to be clouds.

1840. Beer and Maedler published the first map of the planet assigning latitudes and longitudes to the various markings. On this map are indicated the first canals, and the first of the small lakes, so many of which have been discovered during the last few years. The canals are Nectar and Agathodaemon and portions of Hades and Tartarus. The lake is Lacus Phoenicis. Their map is the first satisfactory representation of the entire surface of the planet. The only region which previous observers had clearly distinguished was that in the vicinity of the Syrtis Major.

1858. Secchi made a careful study of the colors exhibited by the planet.

1862. Lockyer made the first series of really good sektches of the planet, showing all the characteristic forms with which we are now so familiar.

His drawings, and also those of some of the other observers, give the first indications of the appearance of the central branch in the Y, so called by Secchi.

1864. Dawes detected eight or ten of the canals.

1867. Huggins detected lines due to the presence of water vapor in the spectrum of Mars.

1867. Proctor determined the period of rotation of Mars within 0.1 second.

1877. Hall discovered the two satellites of Mars.

1877. Green made a very excellent series of drawings of the planet, superior to anything which had preceded them.

1877. Schiaparelli made the first extensive triangulation of the surface of the planet, and added very largely to the number of known canals.

1879. Schiaparelli detected the gemination of Nilus,—the first known double canal.

1882. Schiaparelli discovered numerous double canals, and announced that the appearance formed one of the characteristic phenomena of the planet.

The most reliable confirmation of this phenomenon hitherto reported has come from Perrotin of Nice, and A. Stanley Williams in England. If Schiaparelli's theory is correct, that the duplication occurs only between the spring and autumn equinoxes of the northern hemisphere, the last opportunity to witness it was in 1890, and the next in January and

February of 1895, unless the planet proves to be too remote at that period.

Very few of Schiaparelli's writings have ever been translated into English, and none so far as I know, hitherto, without the intervention of some other language, such as German or French. The following translation is from "Natura ed Arte" for February 15, 1893. It gives the latest expression of his views upon the periodical inundations experienced by the planet, upon the nature of the seas, the canals, and the gemination of the latter.

THE PLANET MARS

GIOVANNI SCHIAPARELLI

Many of the first astronomers who studied Mars with the telescope, had noted on the outline of its disc two brilliant white spots of rounded form and of variable size. In process of time it was observed that whilst the ordinary spots upon Mars were displaced rapidly in consequence of its daily rotation, changing in a few hours both their position and their perspective, that the two white spots remained sensibly motionless at their posts. It was concluded rightly from this, that they must occupy the poles of rotation of the planet, or at least must be found very near to them. Consequently they were given the name of polar caps or spots. And not without reason is it conjectured, that these represent upon Mars that immense mass of snow and ice, which still today prevents navigators from reaching the poles of the Earth. We are led to this conclusion not only by the analogy of aspect and of place, but also by another important observation.

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As things stand, it is manifest, that if the above mentioned white polar spots of Mars represent snow and ice, they should continue to decrease in size with the approach of summer in those places, and increase during the winter. Now this very fact is observed in the most evident manner. In the second half of the year 1892 the southern polar cap was in full view; during that interval, and especially in the months of July and August, its rapid diminution from week to week was very evident, even to those observing with common telescopes. This snow, (for we may well call it so,) which in the beginning reached as far as latitude 70°, and formed a cap of over 2,000 kilometers (1,200 miles) in diameter, progressively diminished, so that two or three months later little more of it remained than an area of perhaps 300 kilometers, (180 miles) at the most, and still less was seen later in the last days of 1892. In these months the southern hemisphere of Mars had its summer; the summer solstice occurring upon

October 13. Correspondingly the mass of snow surrounding the northern pole should have increased; but this fact was not observable, since that pole was situated in the hemisphere of Mars which was opposite to that facing the Earth. The melting of the northern snow was seen in its turn in the years 1882, 1884 and 1886.

These observations of the alternate increase and decrease of the polar snows are easily made, even with telescopes of moderate power, but they become much more interesting and instructive when we can follow assiduously the changes in their more minute particulars, using larger instruments. The snowy regions are then seen to be successively notched at their edges; black holes and huge fissures are formed in their interiors; great isolated pieces many miles in extent stand out from the principal mass, and dissolving disappear a little later. In short, the same divisions and movements of these icy fields present themselves to us, at a glance, that occur during the summer of our own arctic regions, according to the descriptions of explorers.

The southern snow, however, presents this peculiarity, that the center of its irregularly rounded figure does not coincide exactly with the pole, but is situated at another point, which is nearly always the same, and is distant from the pole about 300 kilometers (180 miles) in the direction of the Mare

Erythraeum. From this we conclude that when the area of the snow is reduced to its smallest extent, that the south pole of Mars is uncovered; and therefore perhaps, the problem of reaching it upon this planet is easier than upon the Earth. The southern snow is in the midst of a huge dark spot, which with its branches occupies nearly one-third of the whole surface of Mars, and is supposed to represent its principal ocean. Hence the analogy with our arctic and antarctic snows may be said to be complete, and especially so with the antarctic one.

The mass of the northern snow-cap of Mars is on the other hand centered almost exactly upon its pole. It is located in a region of yellow color, which we are accustomed to consider as representing the continent of the planet. From this arises a singular phenomenon which has no analogy upon the Earth. At the melting of the snows, accumulated at that pole during the long night of ten months and more, the liquid mass produced in that operation is diffused around the circumference of the snowy region, converting a large zone of surrounding land into a temporary sea, and filling all the lower regions. This produces a gigantic inundation, which has led some observers to suppose the existence of another ocean in those parts, but which does not really exist in that place, at least as a permanent sea. We see then, (the last opportunity was in 1884), the white spot of the snow surrounded by a dark zone, which follows its perimeter in its progressive diminution, upon a circumference ever more and more narrow. The outer part of this zone branches out into dark lines which occupy all the surrounding region, and seem to be distributary canals, by which the liquid mass may return to its natural position. This produces in these regions very extensive lakes, such as that designated upon the map by the name of Lacus Hyperboreus; the neighboring interior sea called Mare Acidalium becomes more black, and more conspicuous. And it is to be remembered as a very probable thing, that the flowing of this melted snow is the cause which determines principally the hydrographic state of the planet, and the variations that are periodically observed in its aspect. Something similar would be seen upon the Earth, if one of our poles came to be located suddenly in the center of Asia or Africa. As things stand at present, we may find a miniature image of these conditions in the flooding that is observed in our streams at the melting of the Alpine snows.

Travellers in the arctic regions have frequent occasion to observe how the state of the polar ice at the beginning of the summer, and even at the beginning of July is always very unfavorable to their progress. The best season for exploration is in the month of August, and September is the month in which the trouble from the ice is the least. Thus in September our Alps are usually more practicable than at any other season. And the reason for it is clear, the melting of the snow requires time, a high temperature is not sufficient, it is necessary that it should continue, and its effect will be so much the greater, as it is the more prolonged. Thus, if we could slow down the course of our seasons, so that each month should last sixty days instead of thirty, in the summer in such a lengthened condition, the melting of the ice would progress much further, and perhaps it would not be an exaggeration to say that the polar cap at the end of the warm season would be entirely destroyed. But one cannot doubt in any case, that the fixed portion of such a cap would be reduced to much smaller size than we see it today. Now this is exactly what happens in Mars. The long year, nearly double our own, permits the ice to accumulate during the polar night of ten or twelve months, so as to descend in the form of a continuous layer as far as parallel 70°, or even further. But in the day which follows of twelve months or ten months, the Sun has time to melt all or nearly all, of the snow of recent formation, reducing it to such a small area, that it seems to us no more than a very white point. And perhaps this snow is entirely destroyed, but of this there is at present no satisfactory observation.

Other white spots of a transitory character, and of a less regular arrangement are formed in the southern hemisphere, upon the islands near the pole, and also in the opposite hemisphere, whitish regions appear at times surrounding the north pole, and reaching to 50° and 55° of latitude. They are perhaps transitory snows, similar to those which are observed in our latitudes. But also in the torrid zone of Mars are seen some very small white spots more or less persistent, amongst others one was seen by me in three consecutive oppositions (1877-1882) at the point indicated upon our chart by longitude 268° and latitude 16° north. Perhaps we may be permitted to imagine in this place the existence of a mountain capable of supporting extensive ice-fields. The existence of such a mountain has been supposed also by some recent observers, founded upon other facts.

As has been stated, the polar snows of Mars prove in an incontrovertible manner, that this planet, like the Earth, is surrounded by an atmosphere capable of transporting vapor from one place to another. These snows are in fact precipitations of vapor, condensed by the cold, and carried with it successively. How carried with it, if not by atmospheric movement? The existence of an atmosphere charged with vapor has been confirmed also by spectroscopic observations, principally those of Vogel; according to which this atmosphere must be of a composition differing little from our own, and above all very rich in aqueous vapor. This is a fact of the highest importance, because from it we can rightly affirm with much probability, that to water, and to no other liquid is due the seas of Mars and its polar snows. When this conclusion is assured beyond all doubt, another one may be derived from it, of not less importance,—that the temperature of the Arean climate, notwithstanding the greater distance of that planet from the Sun, is of the same order as the temperature of the terrestrial one. Because, if it were true, as has been supposed by some investigators, that the temperature of Mars was on the average very low (from 50° to 60° below zero) it would not be possible for water vapor to be an important element in the atmosphere of that planet, nor could water be an important factor in its physical changes; but would give place to carbonic acid, or to some other liquid whose freezing point was much lower.

The elements of the meteorology of Mars seem then to have a close analogy to those of the Earth. But there are not lacking, as might be expected, causes of dissimilarity. From circumstances of the smallest moment, nature brings forth an infinite variety in its operations. Of the greatest influence must be the different arrangement of the seas and the continents upon Mars, and upon the Earth, regarding which, a glance at the map will say more than would be possible in many words. We have already emphasized the fact of the extraordinary periodical flood, which at every revolution of Mars inundates the northern polar region at the melting of the snow. Let us now add that this inundation is spread out to a great distance by means of a network of canals, perhaps constituting the principal mechanism (if not the only one) by which water (and with it organic life) may be diffused over the arid surface of the planet. Because on Mars it rains very rarely, or perhaps even, it does not rain at all. And this is the proof.

Let us carry ourselves in imagination into celestial space, to a point so distant from the Earth, that we may embrace it all at a single glance. He would be greatly in error who had expected to see reproduced there, upon a great scale, the image of our continents, with their gulfs and islands, and with the seas that surround them, which are seen upon our artificial globes. There without doubt the known forms, or part of them, would be seen to appear under a vaporous veil, but a great part (perhaps one-half) of the surface would be rendered invisible by the immense fields of cloud, continually varying in density, in form and in extent. Such a hindrance, most frequent and continuous in the polar regions, would still impede nearly half the time the view of the temperate zones, distributing itself in capricious and ever varying configurations. The seas of the torrid zone would be seen to be arranged in long parallel layers, corresponding to the zone of equatorial and tropical calms. For an observer placed upon the Moon, the study of our geography would not be so simple an undertaking as one might at first imagine.

There is nothing of this sort in Mars. In every climate, and under every zone, its atmosphere is nearly perpetually clear, and sufficiently transparent to permit one to recognize at any moment whatever, the contours of the seas and continents, and more than that, even the minor configurations. Not indeed that vapors of a certain degree of opacity are lacking, but they offer very little impediment to the study of the topography of the planet. Here and there we see appear from time to time a few whitish spots changing their position and form, rarely extending over a very wide area. They frequent by preference a few regions, such as the islands of the Mare Australe, and on the continents, the regions designated on the map with the names of Elysium and Tempe. Their brilliancy generally diminishes and disappears at the meridian hour of the place, and is reinforced in the morning and evening, with very marked variations. It is possible that they may be layers of cloud, because the upper portions of terrestrial clouds, where they are illuminated by the Sun, appear white. But various observations lead us to think that we are dealing rather with a thin veil of fog, instead of a true nimbus cloud, carrying storms and rain. Indeed it may be merely a temporary condensation of vapor, under the form of dew or hoar frost.

Accordingly, as far as we may be permitted to argue from the observed facts, the climate of Mars must resemble that of a clear day upon a high mountain. By day a very strong solar radiation hardly mitigated at all by mist or vapor, by night a copious radiation from the soil towards celestial space, and because of that a very marked refrigeration. Hence a climate of extremes, and great changes of temperature from day to night, and from one season to another. And as on the Earth at altitudes of 5,000 and 6,000 meters (17,000 to 20,000 feet), the vapor of the atmosphere is condensed only into the solid form, producing those whitish masses of suspended crystals, which we call cirrus clouds, so in the atmosphere of Mars, it would be rarely possible (or would even be impossible) to find collections of cloud capable of producing rain of any consequence. The variation of the temperature from one season to another would be notably increased by their long duration, and thus we can understand the great freezing and melting of the snow, which is renewed in turn at the poles at each complete revolution of the planet around the Sun.

As our chart demonstrates, in its general topography Mars does not present any analogy with the Earth. A third of the surface is occupied by the great Mare Australe, which is strewn with many islands, and the continents are cut up by gulfs and ramifications of various forms. To the general water system belongs an entire series of small internal seas, of which the Hadriacum and the Tyrrhenum communicate with it by wide mouths, whilst the Cimmerium, the Sirenum and the Solis Lacus are connected with it only by means of narrow canals. We shall notice in the first four a parallel arrangement, which certainly is not accidental, as also not without reason is the corresponding position of the peninsulas of Ausonia, Hesperia and Atlantis. The color of the seas of Mars is generally brown, mixed with grey, but not always of equal intensity in all places, nor is it the same in the same place at all times. From an absolute black it may descend to a light gray, or to an ash color. Such a diversity of colors may have its origin in various causes, and is not without analogy also upon the Earth, where it is noted that the seas of the warm zone are usually much darker than those nearer the pole. The water of the Baltic, for example, has a light, muddy color, that is not observed in the Mediterranean. And thus in the seas of Mars, we see the color become darker when the Sun approaches their zenith, and summer begins to rule in that region.

All of the remainder of the planet, as far as the north pole, is occupied by the mass of the continents, in which, save in a few areas of relatively small extent, an orange color predominates, which sometimes reaches a dark red tint, and in others descends to yellow and white. The variety in this coloring is in part of meteorological origin, in part it may depend on the diverse nature of the soil, but upon its real cause it is not as yet possible to frame any very well grounded hypothesis. Nevertheless, the cause of this predominance of the red and yellow tints upon the surface of ancient Pyrois is well known.[2] Some have thought to attribute this coloring to the atmosphere of Mars, through which the surface of the planet might be seen colored, as any terrestrial object becomes red, when seen through red glass. But many facts are opposed to this idea, among others, that the polar snows appear always of the purest white, although the rays of light derived from them traverse twice the atmosphere of Mars under great obliquity. We must then conclude that the Arean continents appear red and yellow, because they are so in fact.

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[2] Pyrois I take to be some terrestrial region, although I have not been able to find any translation of the name.—Tr.

Besides these dark and light regions, which we have described as seas and continents, and of whose nature there is at present scarcely left any room for doubt, some others exist, truly of small extent, of an amphibious nature, which sometimes appear yellowish like the continents, and are sometimes clothed in brown (even black in certain cases) and assume the appearance of seas, whilst in other cases their color is intermediate in tint, and leaves us in doubt to which class of regions they may belong. Thus all the islands scattered through the Mare Australe and the Mare Erythraeum belong to this category, so too the long peninsulas called Deucalionis Regio and Pyrrhae Regio, and in the vicinity of the Mare Acidalium the regions designated by the names of Baltia and Nerigos. The most natural idea, and the one to which we should be led by analogy, is to suppose these regions to represent huge swamps, in which the variation in depth of the water produces the diversity of colors. Yellow would predominate in those parts where the depth of the liquid layer was reduced to little or nothing, and brown, more or less dark, in these places where the water was sufficiently deep to abosrb more light, and to render the bottom more or less invisible. That the water of the sea, or any other deep and transparent water, seen from above, appears more dark the greater the depth of the liquid stratum, and that the land in comparison with it appears bright under the solar illumination, is known and confirmed by certain physical reasons. The traveller in the Alps often has occasion to convince himself of it, seeing from the summits, the deep lakes with which the region is strewn, extending under his feet as black as ink, whilst in contrast with them even the blackest rocks illumined by the sunlight appear brilliant.[3]

Not without reason then have we hitherto attributed to the dark spots of Mars the part of seas, and that of continents to the reddish areas which occupy nearly two-thirds of all the planet, and we shall find later, other reasons which confirm this method of reasoning. The continents form in the northern hemisphere a nearly continuous mass, the only important exception being the great lake called the Mare Acidalium, of which the extent may vary according to the time, and which is connected in some way with the inundations which we have said were produced by the melting of the snow surrounding the north pole.

To the system of the Mare Acidalium undoubtedly belong the temporary lakes called Lacus Hyperboreus and the Lacus Niliacus. This last is ordinarily separated from the Mare Acidalium by means of an isthmus or regular dam, of which the continuity was only seen to be broken once for a short time in 1888. Other smaller dark spots are found here and there in the continental area, which we may designate as lakes, but they are certainly not permanent lakes like ours, but are variable in appearance and size according to the seasons, to the point of wholly disappearing under certain circumstances. Ismenius Lacus, Lunae Lacus, Trivium Charontis and Propontis are the most conspicuous and durable ones. There are also smaller ones, such as Lacus Moeris and Fons Juventae which at their maximum size do not exceed 100 to 150 kilometers (60 to 90 miles) in diameter, and are among the most difficult objects upon the planet.

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[3] This observation of the dark color which deep water exhibits when seen from above, is found already noted by the first author of antique memory, for in the Iliad (verses 770-1 of book V) it is described how "the sentinel from the high sentry-box extends his glance over the wine-colored sea." In the version of Monti the adjective indicating the color is lost.

All the vast extent of the continents is furrowed upon every side by a network of numerous lines or fine stripes of a more or less pronounced dark color whose aspect is very variable. These traverse the planet for long distances in regular lines, that do not at all resemble the winding courses of our streams. Some of the shorter ones do not reach 500 kilometers (300 miles), others on the other hand extend for many thousands, occupying a quarter or sometimes even a third of a circumference of the planet. Some of these are very easy to see, especially that one which is near the extreme left-hand limit of our map, and is designated by the name of Nilosyrtis. Others in turn are extremely difficult, and resemble the finest thread of spider's web drawn across the disc. They are subject also to great variations in their breadth, which may reach 200 or even 300 kilometers (120 to 180 miles) for the Nilosyrtis, whilst some are scarcely 30 kilometers (18 miles) broad.

These lines or stripes are the famous canals of Mars, of which so much has been said. As far as we have been able to observe them hitherto, they are certainly fixed configurations upon the planet. The Nilosyrtis has been seen in that place for nearly one hundred years, and some of the others for at least thirty years. Their length and arrangement are constant, or vary only between very narrow limits. Each of them always begins and ends between the same regions. But their appearance and their degree of visibility vary greatly, for all of them, from one opposition to another, and even from one week to another, and these variations do not take place simultaneously and according to the same laws for all, but in most cases happen apparently capriciously, or at least according to laws not sufficiently simple for us to be able to unravel. Often one cr more become indistinct, or even wholly invisible, whilst others in their vicinity increase to the point of becoming conspicuous even in telescopes of moderate power. The first of our maps shows all those that have been seen in a long series of observations. This does not at all correspond to the appearance of Mars at any given period, because generally only a few are visible at once.[4]

Every canal (for now we shall so call them) opens at its end either into a sea, or into a lake, or into another canal, or else into the intersection of several other canals. None of them have yet been seen cut off in the middle of the continent, remaining without beginning or without end. This fact is of the highest importance.

The canals may intersect among themselves at all possible angles, but by preference they converge towards the small spots to which we have given the name of lakes. For example, seven are seen to converge in Lacus Phoenicis, eight in Trivium Charontis, six in Lunae Lacus and six in Ismenius Lacus.

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[4] In a footnote the author refers to a drawing of Mars made by himself, September 15, 1892, and says ". . . At the top of the disc the Mare Erythraeum and the Mare Australe appear divided by a great curved peninsula, shaped like a sickle, producing an unusual appearance in the area called Deucalionis Regio, which was prolonged that year so as to reach the islands of Noachis and Argyre. This region forms with them a continuous whole, but with faint traces of separation occurring here and there in a length of nearly 6,000 kilometers (4,000 miles). Its color, much less brilliant than that of the continents, was a mixture of their yellow with the brownish grey of the neighboring seas." The interesting feature of this note is the remark that it was an unusual appearance, the region referred to being that in which the central branch of the fork of the Y appeared. Since no such branch was conspicuously visible this year, it would therefore seem, from the above, that it was the opposition of 1892 that was peculiar, and not the present one.—Tr.

The normal appearance of a canal is that of a nearly uniform stripe, black, or at least of a dark color, similar to that of the seas, in which the regularity of its general course does not exclude small variations in its breadth, and small sinuosities in its two sides. Often it happens that such a dark line opening out upon the sea is enlarged into the form of a trumpet, forming a huge bay, similar to the estuaries of certain terrestrial streams. The Margaritifer Sinus, the Aonius Sinus, the Aurorae Sinus, and the two horns of the Sabaeus Sinus are thus formed, at the mouths of one or more canals, opening into the Mare Erythraeum or into the Mare Australe. The largest example of such a gulf is the Syrtis Major, formed by the vast mouth of the Nilosyrtis, so called. This gulf is not less than 1,800 kilometers (1,100 miles) in breadth, and attains nearly the same extent in a longitudinal direction. Its surface is little less than that of the Bay of Bengal. In this case we see clearly the dark surface of the sea continued without apparent interruption into that of the canal. In as much as the surfaces called seas are truly a liquid expanse, we cannot doubt that the canals are a simple prolongation of them, crossing the yellow areas or continents.

Of the remainder, that the lines called canals are truly great furrows or depressions in the surface of the planet, destined for the passage of the liquid mass, and constituting for it a true hydrographic system, is demonstrated by the phenomena which are observed during the melting of the northern snows. We have already remarked that at the time of melting they appeared surrounded by a dark zone, forming a species of temporary sea. At that time the canals of the surrounding region become blacker and wider, increasing to the point of converting, at a certain time, all of the yellow region comprised between the edge of the snow and the parallel of 60° north latitude, into numerous islands of small extent. Such a state of things does not cease, until the snow, reduced to its minimum area, ceases to melt. Then the breadth of the canals diminishes, the temporary sea disappears, and the yellow region again returns to its former area. The different phases of these vast phenomena are renewed at each return of the seasons, and we have been able to observe them in all their particulars very easily during the oppositions of 1882, 1884 and 1886, when the planet presented its northern pole to terrestrial spectators. The most natural and the most simple interpretation is that to which we have referred, of a great inundation produced by the melting of the snows,—it is entirely logical, and is sustained by evident analogy with terrestrial phenomena. We conclude therefore that the canals are such in fact, and not only in name. The network formed by these was probably determined in its origin in the geological state of the planet, and has come to be slowly elaborated in the course of centuries. It is not necessary to suppose them the work of intelligent beings, and notwithstanding the almost geometrical appearance of all of their system, we are now inclined to believe them to be produced by the evolution of the planet, just as on the Earth we have the English Channel and the Channel of Mozambique.

It would be a problem not less curious than complicated and difficult, to study the system of this immense stream of water, upon which perhaps depends principally the organic life upon the planet, if organic life is found there. The variations of their appearance demonstrated that this system is not constant. When they become displaced, or their outlines become doubtful and ill defined, it is fair to suppose that the water is getting low, or is even entirely dried up. Then in place of the canal there remains either nothing, or at most a stripe of yellowish color differing little from the surrounding background. Sometimes they take on a nebulous appearance, for which at present it is not possible to assign a reason. At other times true enlargements are produced, expanding to 100, 200 or more kilometers (60 to 120 miles) in breadth, and this sometimes happens for canals very far from the north pole, according to laws which are unknown. This has occurred in Hydaspes in 1864, in Simois in 1879, in Acheron in 1884, and in Triton in 1888. The diligent and minute study of the transformations of each canal may lead later to a knowledge of the cause of these facts.

But the most surprising phenomenon pertaining to the canals of Mars is their gemination, which seems to be produced principally in the months which precede, and in those which follow, the great northern inundation, at about the times of the equinoxes. In consequence of a rapid process, which certainly lasts at most a few days, or even perhaps only a few hours, and of which it has not yet been possible to determine the particulars with certainty, a given canal changes its appearance, and is found transformed through all its length, into two lines or uniform stripes, more or less parallel to one another, and which run straight and equal with the exact geometrical precision of the two rails of a railroad. But this exact course is the only point of resemblance with the rails, because in dimensions there is no comparison possible, as it is easy to imagine. The two lines follow very nearly the direction of the original canal, and end in the place where it ended. One of these is often superposed as exactly as possible upon the former line, the other being drawn anew, but in this case the original line loses all the small irregularities and curvature that it may have originally possessed. But it also happens that both the lines may occupy opposite sides of the former canal, and be located upon entirely new ground. The distance between the two lines differs in different geminations, and varies from 600 kilometers (360 miles) and more, down to the smallest limit at which two lines may appear separated in large visual telescopes—less than an interval of 50 kilometers (30 miles). The breadth of the stripes themselves may range from the limit of visibility, which we may suppose to be 30 kilometers (18 miles), up to more than 100 kilometers (60 miles). The color of the two lines varies from black to a light red, which can hardly be distinguished from the general yellow background of the continental surface. The space between is for the most part yellow, but in many cases appears whitish. The gemination is not necessarily confined only to the canals, but tends to be produced also in the lakes. Often one of these is seen transformed into two short, broad, dark lines parallel to one another, and traversed by a yellow line. In these cases the gemination is naturally short, and does not exceed the limits of the original lake.

The gemination is not shown by all at the same time, but when the season is at hand, it begins to be produced here and there, in an isolated irregular manner, or at least without any easily recognizable order. In many canals (such as the Nilosyrtis, for example) the gemination is lacking entirely, or is scarcely visible. After having lasted for some months, the markings fade out gradually and disappear, until another season equally favorable for their formation. Thus it happens that in certain other seasons (especially near the southern solstice of the planet), that few are seen, or even none at all. In different oppositions the gemination of the same canal may present different appearances, as to width, intensity and arrangement of the two stripes, also in some cases the direction of the lines may vary, although by the smallest quantity, but still deviating by a small amount from the canal with which they are directly associated. From this important fact it is immediately understood that the gemination can not be a fixed formation upon the surface of Mars, and of a geographical character like the canals. The second of our maps will give an approximate idea of the appearance which these singular formations present. It contains all the geminations observed since 1882 up to the present time. In examining it, it is necessary to bear in mind that not all of these appearances were simultaneous, and consequently that the map does not represent the condition of Mars at any given period, it is only a sort of topographical register of the observations made at different times of this phenomenon.[5]

The observation of the gemination is one of the greatest difficulty, and can only be made by an eye well practiced in such work, added to a telescope of accurate construction, and of great power. This explains why it is that it was not seen before 1882. In the ten years that have transpired since that time, it has been seen and described at eight or ten observatories. Nevertheless, some still deny that these phenomena are real, and tax with illusion (or even imposture) those who declare that they have observed it.

Their singular aspect, and their being drawn with absolute geometrical precision, as if they were the work of rule or compass, has led some to see in them the work of intelligent beings, inhabitants of the planet. I am very careful not to combat this supposition, which includes nothing impossible. (To mi guardero bene dal combattere questa supposizione, la quale nulla include d'impossibile.) But it will be noticed that in any case the gemination cannot be a work of permanent character, it being certain that in a given instance it may change its appearance and dimensions from one season to another. If we should assume such a work, a certain variability would not be excluded from it, for example, extensive agricultural labor and irrigation upon a large scale. Let us add further that the intervention of intelligent beings might explain the geometrical appearance of the gemination, but it is not at all necessary for such a purpose. The geometry of nature is manifested in many other facts, from which are excluded the idea of any artificial labor whatever. The perfect spheroids of the heavenly bodies and the ring of Saturn were not constructed in a turning lathe, and not with compasses has Iris described within the clouds her beautiful and regular arch. And what shall we say of the infinite variety of those exquisite and regular polyhedrons in which the world of crystals is so rich! In the organic world, also, is not that geometry most wonderful which presides over the distribution of the foliage upon certain plants, which orders the nearly symmetrical, starlike figures of the flowers of the field, as well as of the animals of the sea, and which produces in the shell such an exquisite conical spiral, that excels the most beautiful masterpieces of gothic architecture? In all these objects the geometrical form is the simple and necessary consequence of the principles and laws which govern the physical and physiological world. That these principles and these laws are but an indication of a higher intelligent power, we may admit, but this has nothing to do with the present argument.

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[5] This map may be found also in "La Planete Mars," by Flammarion, p. 440.—Tr.

Having regard then to the principle that in the explanation of natural phenomena it is universally agreed to begin with the simplest suppositions, the first hypotheses on the nature and cause of the geminations have for the most part put in operation only the laws of inorganic nature. Thus, the gemination is supposed to be due either to the effects of light in the atmosphere of Mars, or to optical illusions produced by vapors in various manners, or to glacial phenomena of a perpetual winter, to which it is known all the planets will be condemned, or to double cracks in its surface, or to single cracks of which the images are doubled by the effect of smoke issuing in long lines and blown laterally by the wind. The examination of these ingenious suppositions leads us to conclude that none of them seem to correspond entirely with the observed facts, either in whole or in part. Some of these hypotheses would not have been proposed, had their authors been able to examine the geminations with their own eyes. Since some of these may ask me directly,—Can you suggest anything better? I must reply candidly, No.

It would be far more easy if we were willing to introduce the forces pertaining to organic nature. Here the field of plausible supposition is immense, being capable of making an infinite number of combinations capable of satisfying the appearances even with the smallest and simplest means. Changes of vegetation over a vast area, and the production of animals, also very small, but in enormous multitudes, may well be rendered visible at such a distance. An observer placed in the Moon would be able to see such an appearance at the times in which agricultural operations are carried out upon a vast plain, —the seed time and the gathering of the harvest. In such a manner also would the flowers of the plants of the great steppes of Europe and Asia be rendered visible at the distance of Mars,—by a variety of coloring. A similar system of operations produced in that planet may thus certainly be rendered visible to us. But how difficult for the Lunarians and the Areans to be able to imagine the true causes of such changes of appearance, without having first at least some superficial knowledge of terrestrial nature! So also for us, who know so little of the physical state of Mars, and nothing of its organic world, the great liberty of possible supposition renders arbitrary all explanations of this sort, and constitutes the gravest obstacle to the acquisition of well-founded notions. All that we may hope is that with time the uncertainty of the problem will gradually diminish, demonstrating, if not what the geminations are, at least what they can not be. We may also confide a little in what Galileo called "the courtesy of Nature," thanks to which, some time from an unexpected source, a ray of light will illuminate an investigation at first believed inaccessible to our speculations, and of which we have a beautiful example in celestial chemistry. Let us therefore hope and study.

CHAPTER VIII

THE SEAS OF MARS[1]

The first observation made upon Mars at the Lowell Observatory with the 18-inch Brashear lens was upon June 1, 1894. Since then observations have been continued upon nearly every night. What appears to me to be the most important conclusion deducible from our work so far is that Mars does not always present the same appearance at the corresponding time upon two successive Arean years. This remark does not apply merely to small details but to large and prominent features. Moreover this difference does not seem to be due simply to the fact that one season is a few weeks later than the other, but that the phenomena presented upon the two years are really different.

Thus the central branch of the Y†, just north of Noachis, which was so marked a phenomenon in 1892, was not visible to me early in June, as I had expected it to be. It is true that Mr. Lowell thought he saw it faintly marked, but although I looked for it upon the same evening, I could not satisfy myself of its existence. Nevertheless the definition was such that had it appeared as it did in 1892, it could not have been missed at the first glance. I looked for it again at the following presentation in July just passed, but no trace of it was to be seen. Two drawings made by Professor Campbell upon July 18 and 20, 1892, and published in the last number of the Publications of the Astron. Soc. of the Pacific, p. 171, show it very nicely indeed. These may be compared with some reproductions of my own work originally published in *Astronomy and Astro-Physics*, 1892, p. 668, and now republished in the same number with the drawings of Professor Campbell. After the disappearance of the central branch in the latter part of July, 1892, a portion of it reappeared in August, and remained visible through September. A sketch showing its appearance upon September 4, 1892, has been kindly forwarded to me by Mr. Russell of the Sydney Observatory, N. S. W. This branch may therefore be said to have been characteristic of the opposition of 1892. This same region was very carefully sketched by Mr. Douglass and myself a number of times between June 30 and July 6, 1894, but not a trace of the central branch could we detect. Upon these dates Mars held the same position in its orbit that it did upon August 12 and 18, 1892. A sketch made by myself August 13, 1892, shows the central branch very clearly. It will be interesting to hear if its appearance has been noted this year by the Australian observers, since in their longitude it would have been visible about the middle of June.

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[1] Astronomy and Astro-Physics, 1894, **13**, 553.

† Syrtis Major.

But not only has the central branch of the Y been invisible this year, but the large dark blue patch which it connected with the southern snow cap, and which we called the Northern Sea, has been very much less marked, and much smaller than was the case in 1892.

Again a large black gulf bounding the melting snow upon the north and situated very nearly due south of Syrtis Minor has been a very striking feature of our observations this year. This gulf was only observed once in 1892, upon July 27, and it was then by no means conspicuous. If these very dark regions are, as we suppose them to be, water, it would then seem that the water which did not reach the northern regions this year has appeared as an excess in the south.

Upon testing this black region upon June 4, with an Arago polariscope, made for me by Mr. Brashear, it was found to show clear traces of polarization, as did the canal running north from it. This would naturally be the case if it were water, since being situated near the limb, it would reflect to us largely the light of the Arean atmosphere. Upon the rest of the disc of the planet the polarization was not very conspicuous. At the next presentation of this region upon July 9, the observation was repeated, but to my surprise no trace of polarization in the dark spot could be detected. A close examination of the region was then made, and its color found to have entirely changed,—whereas upon June 9, Mr. Lowell writes "Bay a deep blue, looks just as deep water does," it was now found to be of a rich chocolate brown tint, differing entirely in color from the bluish gray regions to the north of it. These gray regions showed no sign of polarization, and as I have before remarked I see no reason for supposing that their color is due to water. As far as my observations go, it appears to me that the permanent water area upon Mars, if it exists at all, is extremely limited in its dimensions.

These large gray regions were of a brilliant and decided green color in 1890, just before the vernal equinox. In the early part of 1892 also, large green areas were seen upon the planet, but as the season advanced the green regions changed almost entirely to gray. At the present time very little color is visible in the shaded regions. They are subject also to such large variations in area, as the season progresses, that unless we can persuade ourselves that gigantic floods, unaccompanied by clouds, form the normal condition of affairs upon Mars, we seem forced to adopt some other explanation of their existence. The theory that they owe their color to vegetation is perhaps the most plausible one, and some new facts bearing upon this matter have recently come to hand. Upon June 30 a distinct depression in the terminator where it was crossed by the stem of the Y was detected by Mr. Douglass. As the planet rotated, the position of the depression changed, and it was noted that it was not always found in those portions of the terminator which were the darkest. Since that date similar depressions more or less marked have been detected upon nearly every evening. Upon looking over our observations for 1892, I find under date of September 20, 8h. 06m. a drawing showing a flattened terminator, and a statement that "the planet seems somewhat of this shape." Further investigation shows that the long narrow strip known as Ceraunius was lying upon the terminator at about this time. These notches in the terminator can be most readily explained by actual depressions in the surface of the planet, and as Professor Campbell has shown (Pub. Astro. Soc. Pac., 1894, p. 110) a difference of elevation of the surface amounting to two miles ought to be readily visible to us on the Earth at certain seasons provided the elevation or depression involved occurred upon the terminator. It thus appears that we are perhaps on the eve of being able to construct a contour map of the planet. The observations involved are however very difficult, and no great accuracy in the results can as yet be expected.

Strictly speaking the notches in the terminator correspond to variations in the inclination of the surface of the planet rather than to variations in its level, but if we could determine the inclination and knew the distance through which it extended, we should have all the data required for our work.

There is one conclusion however to which these observations lead us at once. Since these notches in the terminator do not necessarily occur in the darkest parts of the grey regions, and since different portions of them are notched to different depths when on the terminator, it follows that all portions of the gray regions are not on the same level. In other words hills and valleys occur in them, and consequently the grey regions do not represent the surface of an ocean.

CHAPTER IX

RECENT STUDIES OF THE MARTIAN AND LUNAR CANALS[1]

It has lately been shown by Messrs. Lane, Maunder, and Evans that many of the finer Martian canals are probably nonexistent, their appearance being due to certain singular optical illusions. Most of the broader canals, however, in the bright regions of the planet, undoubtedly exist, and the same is almost certainly true of the narrower ones in the light regions, such as Nilosyrtis and Nectar. The chief cause of the illusion seems to be the system of lakes, or oases as they are sometimes called, which were first discovered in large numbers at Arequipa. There is a curious tendency of the human eye to see such dark points united by faint narrow lines, and it has been shown by means of diagrams that these lines sometimes appear when the diagram is at such a distance that the dark dots are themselves invisible. But even without the dots the lines may sometimes appear, joining different portions of the dark regions. We must therefore divide the Martian canals into two classes, those that are genuine and those that are not.

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[1] Popular Astronomy, 1904, 12, 77.

Any canal that appears first as a broad streak of measurable breadth, and then gradually narrows as the season progresses may be classed as genuine, although its image may appear by illusion long after the canal itself has really gone. This narrowing of the canals, especially in the bright regions, is very common after the passage of the vernal equinox on Mars. It is also true of several of the canals in the region about Solis Lacus. Any canal on the contrary which suddenly appears as a faint narrow line joining two dark regions may in the future be looked upon with suspicion, even if to the trained eye it is fairly well seen. To this class perhaps belong such conspicuous and well-known examples as Phison, Gehon and Euphrates, besides very many other less observed canals.

This phenomenon of spurious canals is certainly very singular, but we must be careful that its interest and unexpectedness do not lead us into the error of affirming that because many Martian canals are spurious, therefore all Martian canals are imaginary. It seems indeed a great pity that so much time and energy should be expended in many observatories in mapping canals in the bright regions of the planet, and comparatively so little time on

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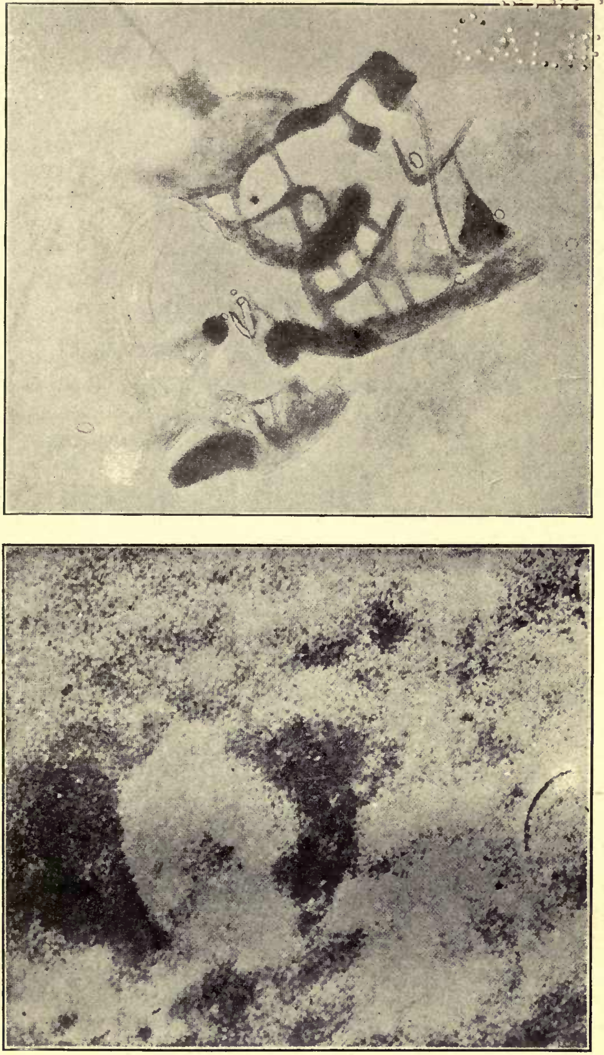

ERATOSTHENES

the darker regions, where changes are constantly taking place, and where we should naturally expect the most interesting developments to occur.

Turning now to the other branch of our subject, we find upon the Moon, where the surface conditions are in some respects similar to those upon Mars, although the atmosphere is probably rarer, numerous canals, which on account of their proximity are much more readily studied than the Martian ones. While from the Harvard station in Southern California photographs of Mars were secured showing the Syrtis Major, the Fastigium Aryn, and other prominent markings, no one has as yet succeeded in photographing fine enough detail to show a Martian canal. On the Moon, on the other hand, a few canals have already been photographed, both at Arequipa and in Jamaica. Recently a fine photograph has been received through the kindness of Professor Hale, which shows several of the canals to much better advantage than any photograph previously taken. Indeed, it may be said that these latest views taken with the Yerkes telescope show nearly all the detail visible with a 6-inch telescope working under very favorable conditions.

For purposes of comparison, I have arranged in the plate a drawing of the canals about Eratosthenes, made in Jamaica, and published in my recent book on the Moon, and an enlargement to the same scale of the same region shown in the Yerkes photograph. The scale is $\frac{1}{2,000,000}$, or about 32 miles to the inch. The drawing was made August 1, 1901, at 8.6 days after sunrise on Eratosthenes, colongitude of the sunrise terminator 116°. The photograph was taken September 2, 1901, 11.3 days after sunrise, colongitude 149°. While therefore it was taken about three days later in the lunation than the drawing, still it does not show any very marked changes to have occurred in the meantime, excepting possibly in the relative intensity of some of the canals. Since the drawing was made only 1.7 days after full moon, when the sun was nearly in the zenith of the crater, and since the same markings are found on other drawings and photographs made at and before full moon, it will be seen that it is geometrically impossible that these markings should be due to shadows. They represent therefore real differences in surface coloration and nothing else.

The other photograph is an enlargement from the same original negative to the same scale. The region shown is situated four diameters, south 20° west, from Eratosthenes. The dark region at the top is in fact the site of Gruithuison's celebrated ruined lunar city. He described a central street from which five or six parallel streets led off on either side at an agle of 45°, like the veins of a leaf. Something of the same sort has been seen by several

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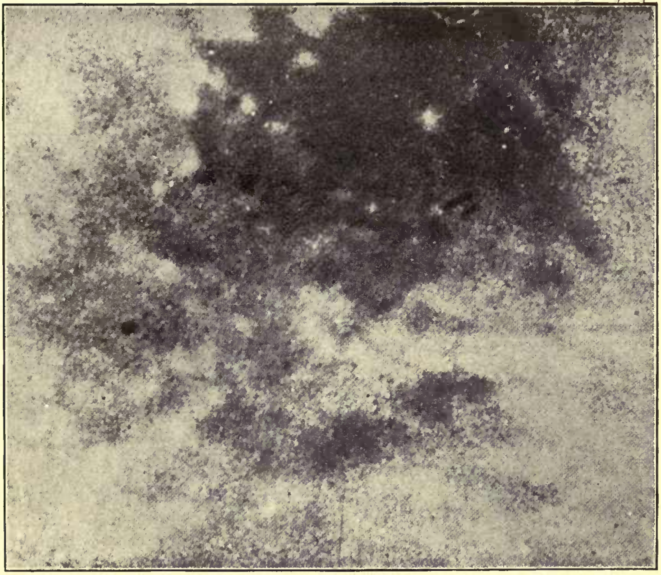

REGION NEAR ERATOSTHENES

other observers, and I have myself seen a few of the lines. The so-called streets are apparently a difficult and very curious combination of ridges. What interests us most, however, is a series of well-marked canals near the center of the view. Just below the center is a white spot. In this is located a Y-shaped combination of canals. From near the foot of the Y a canal leads off to the right, to a very dark spot. This canal is fourteen miles long, and about half a mile in breadth. A short canal branches off from its upper side, i. e., towards the south, and other canals lead off from the dark spot. Below and to the left of this spot is another one of about the same size. Both are suspected of changing the finer details of their shape in the course of the lunation.

In my recent researches I have found, and have endeavored to show, that there is a wealth of fine detail upon the Moon, exhibiting constant variations, of the highest interest to the intelligent selenographer. Of these variations, many it is believed are periodic, while some are wholly irregular in their character. To see them does not involve the use of a large telescope, but it does require a good atmosphere, and also a knowledge of the kind of variations one may expect to observe, and of the sort of places in which they are likely to occur. Without this knowledge much time may be wasted in studying unfavorable localities.

CHAPTER X

AN EXPLANATION OF THE MARTIAN AND LUNAR CANALS[1]

When the suggestion of vegetation was first offered to explain the so-called seas and canals of Mars,[2] the difficulty was strongly felt that while it readily explained their changes of area, shape, and color, it did not satisfactorily explain the long slender forms of the canals. That these might be due to narrow and therefore invisible water courses was an obvious idea. Professor Lowell in adopting these views added to them the hypothesis of an artificial formation. If the canals were really as straight and uniform as they are generally drawn, it was certainly hard to see how they could owe their origin entirely to natural causes. But now that some of the English experimenters, Messrs. Lane, Maunder, and Evans have cast doubt on the existence of many of the straight canals, the hypothesis of an artificial origin is materially weakened.

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[1] Popular Astronomy, 1904, **12**, 439.

[2] Science, 1888, **12**, 82. Astronomy and Astro-Physics, 1892, **11**, 670.

Another difficulty which early presented itself was to explain what caused the water to flow through the narrow channels, unless we supposed it was artificially pumped through them. This has always seemed to the writer to be the chief difficulty with the whole explanation, but Professor Lowell has now courageously taken the bull by the horns, and adopted the pumping hypothesis.[3] If the surface is level, gravity would not come into the question, but we may well ponder upon the amount of energy transformed into work which could furnish enough water to irrigate anywhere from a hundred thousand to a few million square miles of surface.

When the canals on the Moon were discovered, it was thought that they might throw some light upon this puzzling question. It must be remembered that the Moon is about 200 times nearer than Mars at an average opposition, and we can readily imagine that if we could increase the power of our telescopes 200 times, we might make quite a number of interesting discoveries upon Mars.

Upon the Moon as upon that planet, several canals frequently radiate from a single lake, but what was most unexpected, the lakes are sometimes found at the bottom of a lunar valley, and sometimes upon the crest of a crater wall. As is the case with Mars also, when the sun rises upon them, and the snow melts, the lakes and canals develop and become conspicuous, subsequently fading out at sunset, which corresponds to the Martian winter.

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[3] Proceedings Amer. Philosophical Society, 1903, **42**, 364.

It has been shown[4] that in the lunar crater Alphonsus there are eight variable spots, or lakes as we should now call them. In the exact center of each, excepting the largest one, is found a minute craterlet. In the largest lake there are two large craterlets and five small ones. The canals radiate from the lakes and therefore from these craterlets. The symmetrical arrangement of the lakes about the craterlets in so many instances indicates a causal relation between them, and that the vegetation of the lake, if such it be, owes its origin to some volcanic action.

In the case of several of the large craters, notably Tycho, we find a similar radiating structure, and in the case of Tycho even a dark spot or halo at the center. In this case the whole formation is upon so large a scale that its elementary structure can be clearly distinguished. The white radiating lines or bands are seen to be due to numerous minute craterlets, each giving out a triangular white streamer, the alignment of these streamers producing the general effect of a white band. It is probable that this observed regular distribution of the craterlets is due to their lying along invisible cracks radiat-

[4] Harvard Annals, 32, 99.

ing from the main crater. It is much the same as the great volcanoes of the Andes, which stretch in a straight line for over 2,000 miles between Peru and the Straits of Magellan. The Alaskan volcanoes lie upon a uniformly curved line of nearly equal length. Most of the terrestrial volcanoes are distributed along similar lines. This line formation is generally considered by geologists to be due to subterranean lines of weakness or cracks in the earth's crust. Such being the case, it seems probable that the canals on the Moon lie along similar invisible cracks radiating from the small craterlet at the center of each lake. These cracks are not always straight but such is their general tendency. Under favorable illumination small cracks are found to be very common upon the surface of the Moon, and in the cases of Petavious, Alphonsus, and Atlas that class of cracks that we have designated from their shape as river-beds are seen to be intimately associated with the lakes and canals.[5] It is believed that enough water vapor and carbonic acid escape from the central craterlet and flow down its sides to develop the vegetation upon its slopes, and that the smaller quantities escaping from various points along the radiating cracks similarly develop the vegetation which shows along their sides. In addition to the escaping vapor, water itself might issue from the subterranean crack and percolating through the soil be evaporated from its surface.

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[5] **Harvard Annals, 32, 98 and 112, see also Plate VII.**

It is not thought that there is any transfer of vapor lengthwise of the crack but that on account of the lack of external atmospheric pressure the vapor rises quietly directly from the lower regions, owing to the internal heat of the Moon. As soon as the exterior is sufficiently warmed by the sun, the vapor and gas would begin to appear. On account of the rarity of the atmosphere, instead of rising they would immediately spread themselves along the surface of the ground. Even in desert regions upon the Earth we should therefore scarcely expect to find similar formations unless actually irrigated by water, instead of water vapor. In its physical condition Mars seems to occupy an intermediate position between the Earth and the Moon.

It seems to the writer that the merit of this explanation lies not so much in its novelty, but rather because it is founded so largely upon observed facts.

CHAPTER XI

THE DOUBLE CANALS OF MARS [1]

A few years ago the doubling of the Martian canal system was generally admitted by astronomers as an accepted fact. Latterly however doubts have begun to arise with regard to it. It was shown by the writer, in the Harvard Annals XXXII, 149, that accepting the results of Schiaparelli, Flammarion, Antoniadi and Lowell, the double canals had this curious property, namely, that their linear separation was inversely proportional to the diameter of the object-glass of the telescope, and directly proportional to the distance of the planet.

It was then suggested that some one who was able to see the duplication of the canals, which the writer has never been able to do, should make measures of their separation, using different apertures in front of the telescope upon the same night. This has now been done by Professor Lowell, Bulletin 5, Lowell Observatory, and a recent examination of his work, has shown that he has brought out some very instructive results.

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[1] Popular Astronomy, 1904, **12**, 385.

In the first place as far as he is concerned it is evident that the separation of the canals is independent of the aperture of the telescope employed. Secondly, he has found that the duplication of the canals can be seen with surprisingly small apertures. Thus with six inches he divides the three double canals Euphrates, Hiddekel, and Gihon when their components were separated only 0″.27, 0″.26, and 0″.28 respectively.

It was found by Dawes that an objective one inch in diameter could separate (not merely elongate) two equal stars 4″.56 apart. A 6-inch objective should therefore separate stars at one-sixth this distance, or 0″.76. Experiments made at Cambridge with a 15-inch aperture Harvard Annals XXXII, 149, showed that in order to divide two lines drawn in ink on white paper, they must be separated by an angle of 0″.42. For a 6-inch objective the required separation would therefore be 1″.05.

An analogous experiment may be readily repeated without instruments. Draw two lines in ink 1 millimeter, or one twenty-fifth of an inch apart, on white paper. Placed at a distance of ten feet they can just be divided with the naked eye. Their separation will be 70″. The diameter of the pupil of the eye in a brightly lighted room is about one-tenth of an inch. If we can conceive the pupil enlarged sixty times, which is what is practically done by a 6-inch telescope, we should be able to separate the lines at one-sixtieth of this distance apart, or at 1″.15.

Summarizing our results, and applying them to the case of a 6-inch telescope, we find from Dawes' experiments, confirmed universally by astronomers, that two stars could only be separated when as much as 0″.76 apart. The less the contrast the more difficult the separation. Therefore for black lines on white paper we need a greater separation than in the case of the stars. Our telescopic experiments with black lines indicate that the angle must measure 1″.05. Our naked eye experiments make the angle 1″.15. In the case of Mars, Professor Lowell can detect the duplication when the separation is only 0″.26. This would be equivalent in the case of the naked eye experiment to separating two lines one millimeter apart at a distance of forty feet. This the reader will find is quite impossible.

The writer hesitates to believe that Professor Lowell can separate two actual lines which are so much nearer together than the limit for other observers, and thinks therefore that what he sees must be some optical illusion.

CHAPTER XII

THE EXPECTED MARTIAN SNOWS[1]

It may interest observers to know that ice will probably begin to form at both poles of Mars during the month of April. The north pole will be turned toward the Earth at an angle of from 10° to 13° during the month, and the meteorological changes that we may expect to see when the ice appears should be quite conspicuous, the northern ice melting rapidly in the continuous sunshine. The poles may appear either a pure white, a light yellow or a bright but vivid green. The first indicates hoar frost or snow, the second clouds, and the third, at least in part, vegetation. The green over a considerable portion of the planet will be particularly vivid during the present opposition, and should be visible even in small telescopes. A paper on Martian Meteorology is now in preparation for the Harvard Annals treating this subject in more detail, but it probably will not be ready for distribution before summer.

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[1] Popular Astronomy, 1905, **13**, 196.

The planet will be from 13″ to 17″ in diameter, coming to opposition early in May, so that the disc will be large enough to be well seen. Indeed, this opposition will be particularly favorable to these observations, the planet being nearer us and better placed during this portion of its year, than during either the preceding or following oppositions. It is unfortunately rather far to the south, declination —18°, and observations at the beginning of the month cannot be made much before midnight,—meridian passage 14h. 53m. By the end of the month observations may begin shortly before ten o'clock, —meridian passage 12h. 39m.

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In the April number of *Popular Astronomy* attention was called to this planet, and the opinion expressed that the polar caps should appear during the month. Owing to the press of other matters it was not possible to maintain visual observations in Cambridge, but photographs were obtained under the direction of Mr. King with the 11-inch Draper telescope whenever practicable. An enlarging lens was employed, giving the original negative on a scale of about 2.″5 to the millimeter.

The first photograph was taken upon March 31, others being secured upon April 1, 2, 8, 15, 16, 18, 23, 25, 27, and 30. The first photograph showed clouds at both the limb and terminator, but no polar caps properly so-called appeared until April 23, when a large light area was clearly visible at the south pole. It did not appear bright enough for snow, however, but more resembled an extensive cloudy region. It has remained visible upon the photographs since that date, although with slightly diminished intensity and size. A minute bright area appeared near the north pole on April 15, but was seen only with difficulty.

A visual examination of Mars was made on the night of April 30, with the 24-inch reflector. The southern polar cap was clearly visible, extending far to the north in longitude 340°, but its intensity was slight, little exceeding that of the limb in other regions. It is probable that when the Martian clouds clear away, snow will be found lying in their place.

The heliocentric colongitudes of the planet upon April 15 and 23 were 216° and 220°. These positions would correspond on the Earth to August 3 and 7, or to near the end of the winter of the southern hemisphere. Snow seldom comes earlier upon Mars. Extensive green areas should be visible in June, and the Mare Erythraeum recently described by Professor Lowell as brown, should by that time have recovered its normal color. This change of color with the seasons seems to the writer the best proof of the existence of vegetation on Mars.

CHAPTER XIII

WHAT WE KNOW ABOUT MARS[1]

During the next three years the planet Mars will twice approach nearer to the Earth than has been the case since 1892. It will, therefore, be a very conspicuous object in the heavens, equaling Jupiter in brilliancy, and will excite considerable attention from astronomers in various parts of the world.

THE ORBIT OF MARS

To understand why, unlike the case of the other planets, these near approaches occur only at such long and irregular intervals, let us imagine the larger circle (Fig. 1) to represent the orbit of Mars, and the smaller one the orbit of the Earth, the Sun being at *S*. These orbits are not really circles, but ellipses, the Sun being a little to one side of the exact center in each case. The intersections of the two inclined diameters *P A*, *pa*, with the orbits, show where the planets are nearest and farthest from the Sun. When Mars is nearest the Sun it will be seen that the Earth is nearly at its greatest distance, which brings the two orbits closer together there than elsewhere.

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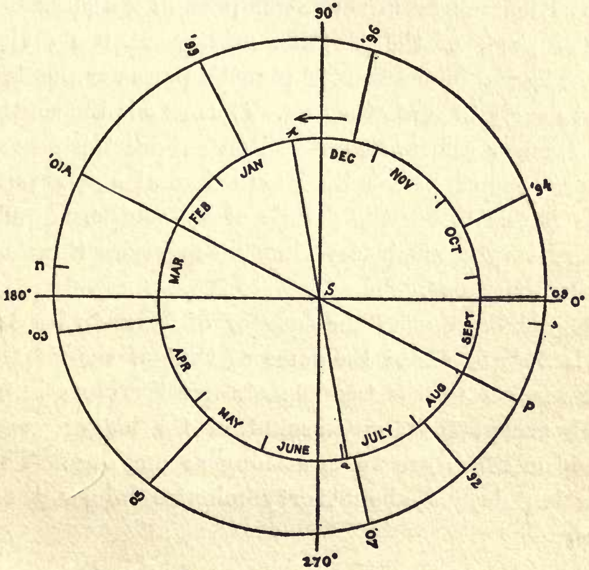
[1] The Technical World Magazine, 1906, 460.

The Earth moves in its orbit much faster than Mars, and also has a shorter distance to travel; it therefore overtakes Mars once in a little over two years. When this is the case, the two planets are much nearer together than at other times. Mars then rises just at sunset; and since it is in the op-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JULY
JUNE

FIG. 1. ORBITS OF THE EARTH AND MARS

posite part of the sky to the Sun, it is said to be in *opposition*. In the figure, the short lines connecting the two orbits show where the different oppositions have occurred. In that of 1892, the two planets were very near together; in 1894 they were somewhat farther apart; but no favorable opposition has occurred since then. The next one will take place in 1907, and will be a little better than that of 1894. The distance of Mars from the Earth will then be 38,200,000 miles, while the shortest possible distance is 35,000,000 miles. The most favorable oppositions occur in the latter part of August.

The parts of the Martian orbit marked *n* and *s* in the figure, show when the planet's poles are pointed most nearly towards the Sun. Thus at *s* is the southern summer and northern winter. Since the planet is here so much nearer the Earth than at *n*, it is possible for us to see the details of its southern hemisphere very much better than we ever can those of its northern one.

The inclination of the equator of Mars to its orbit is 24°, or about the same as that of the Earth. The seasons on the two planets are therefore identical, except that, on account of the longer year, those on Mars are twice as long as our own. The Martian day is about forty minutes longer than ours.

GRAVITATION, WATER, AND ATMOSPHERE

The diameter of Mars is 4,200 miles, or a little over half that of the Earth. Its mass, or the amount of matter it contains, is 0.12 as compared with that of the Earth; and the force of gravity at its surface, 0.38, or about two-fifths that at the surface of the Earth. A man weighing 150 pounds on the Earth would weigh rather less than 60 pounds on Mars, and could accordingly be much more active. He could jump much higher and throw a stone two and a-half times as far. It will be noticed that he could not move the stone any faster than he could upon the Earth; merely, it would take longer to fall, and therefore would go farther before striking the ground.

The effect of this small constant of gravitation has a most important influence on the physical conditions at the surface of Mars. Bodies where this constant is large, like the Sun and stars, can retain enormous atmospheres of the lighter gases, like hydrogen and helium, which escape at once into outer space from the Earth's atmosphere. Bodies where the constant is small, like our Moon, lose nearly all their atmosphere, save such components as are being constantly liberated from their interior, like water vapor and carbonic acid. Mars, where the constant of gravitation lies between those of the Earth and Moon, must have an atmosphere intermediate in its density and composition. That its atmosphere contains water vapor, we know, because we see it frozen at its poles in the form of ice, and later melted to form water. It is sometimes suggested that this white material, which increases in winter and diminishes in summer, may be carbonic acid; but this cannot be the case, since carbonic acid does not become liquid at pressures of less than five atmospheres, no matter what the temperature may be. The atmosphere of Mars, we know, is very rare; therefore the liquid we see surrounding the melting ice-caps cannot be carbonic acid. There is no substance known, save water, that would meet these conditions; therefore, if the polar caps of Mars are not due to ice, they must be caused by some substance that is not found upon the earth—which conclusion is improbable.

Water is nevertheless very scare on Mars; and its oceans, if it has any, are shallow and only temporary, existing solely at the times of the spring freshets. In Fig. 2 is shown the south polar cap after the ice has begun to melt. Below, and to the right of it, is seen a very dark area, which the polariscope shows differs from the rest of the planet in

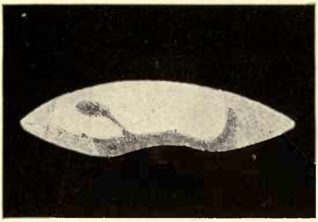

FIG. 2. SOUTH POLE OF MARS
Showing White Polar Cap. From a drawing by the writer

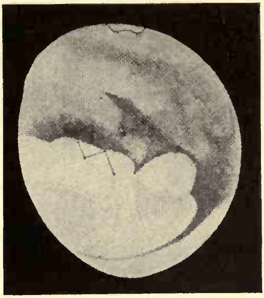

FIG. 3. REGION ABOUT SYRTIS MINOR, SHOWING SOME SHORT AND EXTREMELY NARROW CANALS
A lake near center of one of the seas is also shown, just above center of the figure. From a drawing by the writer in 1894

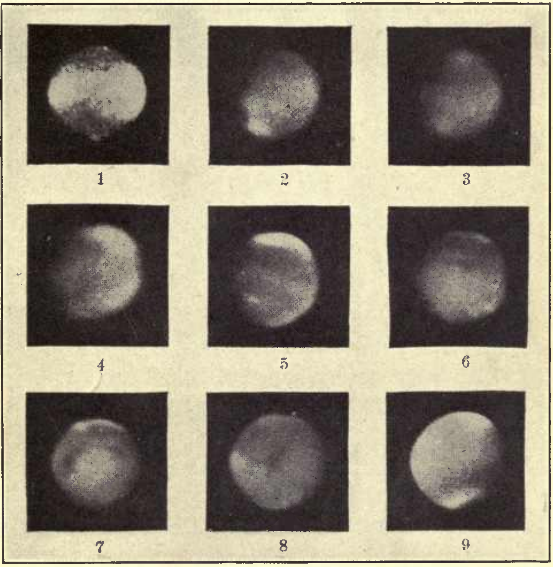

FIG. 4. PHOTOGRAPH OF MARS TAKEN AT HARVARD OBSERVATORY AND THE HARVARD STATION ON MOUNT WILSON IN SOUTHERN CALIFORNIA IN 1888 AND 1890

that it has a shiny surface.[2] In the springtime, shortly after the ice has begun to melt, this dark area forms a ring surrounding the ice, measuring some two thousand miles in diameter and in some places over two hundred miles in breadth. As the ice-cap diminishes in size, the black border retreats with it towards the pole. This leads us to believe that the black area is due to a swamp or a collection of swampy pools and streams, rather than a sea. Within the ice-cap is seen a lake connected with the swamp by a narrow strait.

If the ice-cap, when at its maximum size, contains the larger part of the total water supply of the planet, it will not be difficult to form an idea of its volume. Let us assume that the mean depth melted by our Sun in four of our months over the whole area is twenty feet, and that the ice has the consistency of snow. This, when melted, would give us a lake 2,000 miles in diameter and two feet in depth. This would be about the amount of water contained in one of our great lakes. One thousand times this amount would be insignificant compared to our terrestrial oceans.

Probably water would not now be found on the planet at all, if, as in the case of our Moon, it were not constantly renewed from the interior. Fresh supplies are thus gradually taking the place of that which is being slowly dissipated into space. Sooner or later these supplies must be exhausted; and then, if not before, all life on both these bodies must cease. On our Earth too, when our volcanoes cease to evolve carbonic acid, plant life, and with it all animal life, must necessarily come to an end.

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[2] Astronomy and Astro-Physics, 1894, **13**, 554.

Oxygen and nitrogen may exist upon Mars, but probably in small quantities. Campbell has shown by spectroscopic evidence, that the density of the Martian atmosphere cannot exceed one-quarter that of our own, and is probably much less. The existence of water in the liquid form shows that the density of the Martian atmosphere must exceed 1-150 that of the Earth. As far as we know at present, therefore, the equivalent pressure of the Martian atmosphere is less than 7.5 inches, and is more than 0.2 inch. The light and absorption visible at the bright edge of Mars indicate that the true value lies nearer to the upper of these limits than it does to the lower one. The lowest pressure at which man can live, as shown by recent experiments made by inhaling oxygen and carbonic acid combined, is about 5 inches; and that is probably only for a short time; but doubtless an intelligent race might be slowly evolved, capable of sustaining life at still lower pressures.

CLIMATE AND METEOROLOGY

The fundamental fact on which we must base our knowledge of the climate of Mars, is the melting of its polar snows. Where these are melting, the temperature must be 32° F.; and nearer the equator it must be warmer. The climate of the Earth is tempered by our great oceans. Otherwise our summers would be much hotter, and our winters much colder. In the heart of the continents, the extremes are much greater than on the coast. On Mars, where there are no permanent oceans, the extremes must be greater still. Our atmosphere also serves to moderate our climate. On high mountain summits, the extremes are much greater than at sea-level. The comparatively rare atmosphere of Mars must be of little use in this respect.

Certain causes tend to raise the mean temperature of Mars. The relatively large amount of cloud and illuminated snow areas of the Earth, cause a great waste of heat by reflection, which does not occur upon Mars. If the nights of Mars are comparatively cloudy, as may be the case, these clouds would help to protect the planet from radiation into space during that portion of the Martian day, and thus also tend to raise its temperature.

In the summer season, on account of the rare atmosphere and the lack of water, the arctic regions on Mars must enjoy a temperature but little lower than that of the torrid zone, but during the long winter night the polar cold must be intense, and but little removed from absolute zero—that is —460° F. As to the highest temperature experienced on Mars, we have no information, but may suppose it to be inferior to that found upon the Earth. In the torrid zone, humanity would possibly find the range of temperature disagreeable, but probably not unbearable. Even in the polar regions, vegetation, if not animal life, might exist, much as it does with us.

The clouds of Mars for some unknown reason appear yellowish in color. On the surface of the disc, although visible, they are not conspicuous, but can readily be photographed. On the terminator they are at certain seasons easily seen. In the opposition of 1894, many were recorded at Flagstaff. The projection on the left-hand side of Fig. 3 is due to cloud. Only three clouds are on record which could be identified upon two successive nights. These all were discovered at Flagstaff, and were seen in the years 1894,[3] 1900,[4] and 1903.[5] They appeared in what would correspond to the late summer or autumn upon the planet, two within and one near the borders of the torrid zone, all within 60° of the Sinus Sabæus. They were all three at an altitude of about fifteen miles, and moved in a general northwesterly direction, with velocities of from 13 to 27 miles per hour. These altitudes are much greater than those of terrestrial clouds, while the velocities indicate a comparatively sluggish atmospheric circulation, which is what we should expect.

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[3] Astro-Physical Journal, 1895, **1**, 127; also "Mars," P. Lowell, 70.

[4] Proceedings, American Philosophical Society, No. 167, page 166.

[5] Lowell Observatory Bulletin No. 1.

The nine photographs shown in Fig. 4 are the first ones ever taken showing detail upon Mars. Drawings and photographs of the planets are always turned so that south shall be at the top. The right-hand side is called east. The bright edge is called the "limb"; the dark edge, which is where the Sun is rising or setting, is called the "terminator."

The first photograph shows the equatorial cloud-band. The second shows the north polar cap. The third was taken the next day, and shows the formation during the twenty-four hours of a new south polar cap. The fourth was taken five days later, and shows the increase in size of this cap. The fifth photograph shows the cap well developed, also a faint equatorial cloud-belt, and below it one of those mysterious white spots which are never found far from the equator. Unlike the clouds, these spots do not change their position, but persist for long periods of time. This one was still visible, although faint, at the end of six weeks. There are no mountains on Mars to collect clouds, save possibly a short range near the south pole. It does not seem likely that this spot was due either to ice or to clouds. It was located near the Trivium Charontis, in longitude 205°, latitude + 15°. A similar though less conspicuous white spot had been observed on the equator in longitude 300°, in 1892, at Arequipa, and in 1901 and 1903 at Flagstaff. The spot near the Trivium is visible only during the summer season on Mars, its first recorded equivalent date of visibility being June 2, and the last September 13. It is possibly due to vegetation. If so, it is perhaps appropriate that Schiaparelli should have designated this region under the name "Elysium."

The ninth photograph shows the decreasing size of the southern ice-cap, while a temporary belt of cloud surrounding the north pole is also shown. A study of photographs like these enables us to determine the duration of the cloudy and clear spells upon Mars. Continuous cloudy weather near the equator or tropics is very rare, but in the polar regions the clouds frequently last for weeks at a time. The intervening periods of clear weather are also of long duration.[6] The three remaining photographs show permanent details upon the disc. The dark spot just above the middle of the sixth view is the Sinus Sabæus, from which Martian longitudes are reckoned. The dark spot on the two others is the Syrtis Major.

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[6] Annals, Harvard College Observatory, **53**, 166.

SEAS, CANALS, AND LAKES

The first drawing ever made of a dark area or sea on Mars was of this same Syrtis Major, by Huygens, in 1659. The first map showing a canal and lake was constructed by Beer and Maedler in 1840. The canal was Dæmon; the lake, Lacus Phœnicis. The canals were first recorded in large numbers by Schiaparelli in 1877; the lakes, at the Harvard station in Arequipa in 1892, when forty of them were observed.

A large telescope is not necessary in order to see clearly the canals and lakes. One of eight or ten inches aperture is ample. The really important requisite, however, is a steady atmosphere, such as is found only in low latitudes, which gives what astronomers technically call "good seeing." This explains why it is that Mars cannot be studied to advantage at the large northern observatories, where, with the most superb optical equipment, little or nothing save the coarser detail can be seen upon its surface.

Doubt has recently been expressed, in some of the foreign periodicals, even as to the existence of the canals. An astronomer who has never looked through a telescope, except in northern Europe or the eastern United States, has no right to express any opinion on the subject, because he simply does not know what good seeing looks like, and his opinion is therefore valueless. He might as well express his views on electro-dynamics or physiology. The comparatively small number of astronomers who are familiar with good seeing, and have looked at Mars, have seen the canals, and consequently do not doubt their existence.

Our present telescopes are plenty large enough for purposes of planetary research; indeed, some of them are too large, and no gain can be secured by trying to improve them. In Cambridge an aperture of 6 inches will show everything on the Moon or Mars that can be seen with a 15-inch telescope. At Flagstaff, where the seeing is much better, Professor Lowell has stated that he often reduces his aperture from 24 to 16 inches in order to see more distinctly. What we must now do is to try to find places on the Earth where the seeing is better than anything yet discovered, and erect our future telescopes there. Then we can perhaps use still larger apertures to advantage. Heat or moisture have nothing whatever to do with the seeing; it is chiefly a question of latitude; and in low latitudes, such as Arequipa

— 16°, and Flagstaff + 36°, the seeing is often very good indeed. The reason of this is that these places are far removed from the great cyclonic disturbances which affect our atmosphere in the temperate zones. At these places, the canals of Mars are perfectly distinct. To understand how the planet appears there through a large telescope, we may examine the Moon some night through a small opera glass. The sharpness and amount of detail visible in the two cases will be similar, although the appearance of the two bodies is quite unlike.

In former times the red color of the planet was supposed to be due to its atmosphere. Later it was seen that this was impossible. The dark spots on its surface were next thought to be water, and were called seas; while the bright red areas were supposed to be due to vegetation, which it was imagined must be of that color upon Mars. Later the writer suggested that the so-called seas and canals were the real vegetation, the red areas being desert regions.[7] This view was strongly confirmed by the Arequipa observations of 1892, and the Flagstaff observations of 1894, and has since been generally adopted, although the old names, for the sake of their convenience, are still retained.

One out of several difficulties in supposing that the seas and canals are due to water, is that many of the canals cross the seas, which it is difficult to explain on that hypothesis (see Figs 5 and 11). Some of the lakes on the planet, also, are located in the seas. The latter are found to be a vivid green in what corresponds to the springtime of Mars. Afterwards they turn grey; and still later those of them near the poles become yellow. They are then distinguished only with difficulty from the soil of the desert regions of the planet. In a recent observation made at this season by Lowell at Flagstaff, the Mare Erythræum was found to have turned a chocolate brown, a color which on the Earth we should associate with fertility. The writer has seen the same color exhibited at the time of the drying up of the temporary south polar ocean. The canals are usually too narrow to have any appreciable color, although in the case of the broader ones their color is thought sometimes to resemble that of the seas. Sometimes it is described by both Schiaparelli and Lowell as brown.

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[7] Science, 1888, **12**, 83. Astronomy and Astro-Physics, 1892, **11**, 670.

Their breadth is very uncertain; some observers like Douglass draw them very wide (see Fig. 5); others like Lowell, from whose drawing Fig. 6 is copied, extremely narrow. The writer gives them an intermediate breadth (see Fig. 10). Occasionally, with conditions favorable to the best seeing, short and extremely narrow canals have been seen by the

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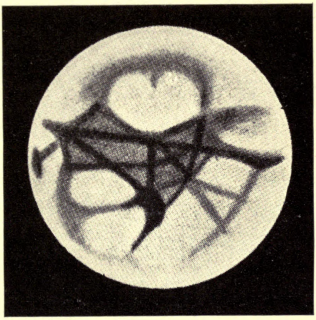

FIG. 5. REGION ABOUT SYRTIS MAJOR
Drawn by A. E. Douglass

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writer (Fig. 3); but the long canals never appear to him as narrow as they are drawn by Lowell.

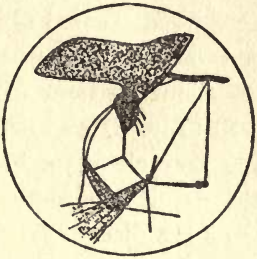

FIG. 6. REGION ABOUT SYRTIS MAJOR
From a drawing by Professor Lowell.

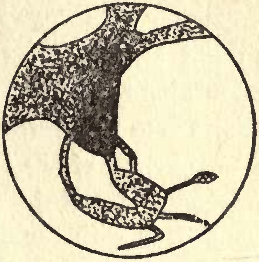

FIG. 7. MARKINGS ON THE SURFACE OF MARS
Drawn by writer from two photographs taken at Flagstaff.

Recently Mr. Lampland at Flagstaff has succeeded in photographing some of the canals. At first it was supposed that these photographs would serve to convince the doubters of their existence; but it was soon found that those who doubted the canals were also unable to see them on the photographs, so that the photographic argument seemed to have a minus value. Photographically the canals are extremely difficult objects, and it does not surprise the writer that those unused to astronomical photographs, could not make them out.

A drawing from the photographs was made by Mr. Wesley and published in *The Observatory* the past year. Fig. 7 is a drawing by the writer, based chiefly on the third, but partly on the first photograph issued in Bulletin No. 21 of the Lowell Observatory. The other photographs were also consulted, and no marking was considered assured which did not appear upon at least one of the others. These photographs were taken about an hour after the drawing by Professor Lowell (Fig. 6) was made. A comparison of the two shows very clearly a tendency on his part to draw the detail too small, in comparison with the diameter of the disc.

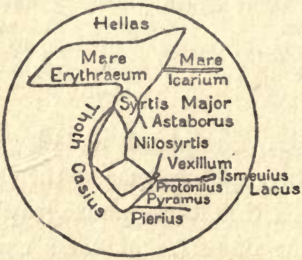
Hellas
Mare Erythraeum
Mare Icarium
Syrtis Major
Astaborus
Thoth
Nilosyrtis
Vexillum
Ismeuius Lacus
Casius
Protonilus
Pyramus
Pierius

FIG. 8. KEY MAP GIVING NAMES OF CANALS AND OTHER FEATURES

Fig. 8 will serve as a key to the names of the canals discussed, which Lowell states are visible on the photograph. The main features—Hellas, Mare Erythræum, Mare Icarium, and Syrtis Major—are all obvious on the originals from which Fig. 7 was sketched. The canals Nilosyrtis, Casius, and Pyramus are also perfectly clear, but, it will be noticed, do not appear on the photograph as canals at all, but as broad areas. Regarding the last two, this is true also of Lowell's drawing. His drawing of the first is certainly too narrow, as proved by the photographs. Of the remaining canals described by him—which come down as narrow lines in the photograph—Thoth, Astaborus, and Protonilus are fairly clear. Vexillum, Pierius, and Ismenius Lacus are more difficult, but apparently shown.

As a photographic triumph, these results are well worthy of record; and when we consider how difficult it is to photograph fine detail that is not merely obvious but even conspicuous to the eye, the photographs bear strong testimony to the distinctness with which the canals must have been visible at Flagstaff on the day in question.

Intermediate between the doubters and Professor Lowell's immediate following, there is a large class of persons who deny some of the fainter canals, and who doubt the uniformity of structure of the others. They say his canals are too regular, too narrow, and too straight—that if they were better seen they would be found to be made up of short broken lines of varying width, and perhaps, in places, of irregular spots. This proves to be the case with the lunar canals. With poor seeing and a low magnification, they seem to be perfectly smooth and straight, like the Martian ones; but with good seeing and a higher power, they are found to be quite irregular. Why should it not be true also on Mars? To this, Mr. Lowell replies that the lunar canals consist of dark markings lying along natural cracks, while the Martian canals are artificial. This may be so, but it would be hard to prove it.

Again, amidst numerous irregular and nearly invisible markings, the human eye, when straining for the faintest possible detail, naturally connects conspicuous objects by straight lines. Is it not possible therefore that many of these fainter canals are merely subjective effects?

The point of all this criticism is that the numerous long, straight lines give the planet a very artificial appearance. If the lines were more broken and irregular, they would look more like natural markings, more in fact like what we find upon the Moon. In short, the argument in favor of intelligent inhabitants would be greatly weakened.

DUPLICATION OF THE CANALS

In 1882, Schiaparelli announced that the canals in Mars were sometimes double. One day a canal would be clearly seen, on the next day, or even a few hours later, there would be two in its place. Later the two would disappear, and again the canal would be single. Sometimes the single canal would coincide with one of the pair, but more frequently it would coincide with neither of them. When we consider that these double canals were often as much as 200 miles apart, these sudden changes seemed incredible.

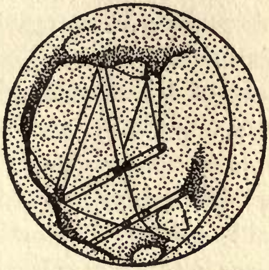

FIG. 9. DUPLICATE CANALS, FROM DRAWING BY PROFESSOR LOWELL

Opposition of 1903. Sinus Sabæcus is near top of disc; Syrtis Major on the left.

When Lowell confirmed the duplication of the canals (see Fig. 9), many astronomers hesitated to accept it. In fact his observations even seemed to make it still more improbable. He measured their separation with telescopes of different apertures, and succeeded in seeing the duplication when both by theory and observation it should have been invisible. Moreover, with a few exceptions, the only drawings he published showing the double canals were made by himself; and these exceptions were mostly made by Douglass, who, in the published text, expressed grave doubts as to the objective reality of the duplication. It is true, several other observers using much smaller telescopes claimed to see it; but it always happened to be just at the limit of visibility of their telescopes, no matter what the size of their instruments chanced to be. One of the most skilful of these observers, M. Antoniadi, later published his doubts as to the genuineness of what he had seen. On the other hand, most of the observers who used large telescopes always saw the canals single. Naturally the astronomers were not convinced.

Now further observations have been made, and new facts brought to light that partially explain this singular phenomenon. According to Professor Lowell only about one-quarter of all the canals are ever seen to be double, and they are probably double all the time.[8] It is only when they are very faint that they appear single, and their faintness is apparently the reason that the duplication does not then show. This is due to the fact that under these circumstances one canal is somewhat fainter than the other, and so escapes detection. According to his views, the single canal always coincides in position with one of the two components of the double.

The double canals usually appear, he says, as a broad, hazy band; it is only by glimpses that the duplication is seen. There is nothing improbable in the idea that one-quarter of the canals should be

[8] Lowell Observatory Bulletin No. 15.

permanently broad and the rest permanently narrow. The only question is, Is it likely that either the middle of these canals should fade out, leaving the sides dark, or that the sides should darken, leaving the middle bright?

It is a fact that some of the seas, as the season progresses, will fade out across the middle in places, leaving the rest dark, and thus present on a comparatively large scale a phenomenon similar to that claimed for the double canals. This same effect occurs upon the floor of the lunar crater Eratosthenes, forming two widely diverging canals. A long, double canal is also found upon the rim of this crater, but this is clearly due to the presence of two long, parallel cracks. A similar chance occurrence might occasionally be found upon Mars, but it seems to the writer in the light of the facts, and especially of the opinions of Messrs. Douglass and Antoniadi, that the case for a systematic duplication will not be proved until more well-known observers, favorably situated and circumstanced, have recorded it.

SEASONAL CHANGES

Perhaps Lowell's most interesting recent investigation is on what he calls the Cartouches of the Canals—that is, their variable visibility dependent on the Martian seasons.[9] He finds that soon after the begnining of the melting of the northern ice-cap, the canals begin to develop in the north polar regions. These are immediately followed by the canals in the north temperate zone. A few weeks later, those in the torrid zone develop; and still later, those in the south temperate. The process of development, therefore, is carried on across the equator. This is most naturally explained by the growth of vegetation following the annual transference of water from pole to pole. The speed of transfer he finds is at the rate of two miles per hour.

The striking difference between Mars and our planet is that in our equatorial regions, where we have plenty of water, there is continued fertility throughout the year. On Mars the vegetation must wait until the water reaches it semi-annually from the poles. There are accordingly two fertile and two barren seasons.

Professor Lowell concludes that the water is transferred artificially from pole to pole. In this we can hardly follow him, since with the rare atmosphere, and accordingly rapid evaporation and condensation upon Mars, the aqueous vapor would necessarily flow across the planet's surface of itself, being alternately condensed at each pole by the winter's cold.

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[9] Lowell Observatory Bulletin No. 12.

A curious feature of the canals and other markings is that they do not always present the same appearance at the same equivalent time in successive Martian years. Thus, a certain marking called by Schiaparelli "Lacus Mœris" could not be found at all at Arequipa in 1892. After an interval of thirteen years since it had last been seen, it reappeared with perfect distinctness in 1903, and was observed by Lowell.[10] A very marked change in the Deucalionis Regio, observed in 1892 in connection with the melting of the ice-cap, did not take place again at the same equivalent season in 1894; nor has it been observed since. A certain canal observed by Schiaparelli was not found at all by Lowell, another one having replaced it. This latter only recently disappeared, Schiaparelli's original canal having taken its place.

IS THE PLANET INHABITED BY INTELLIGENT BEINGS?

There is little doubt now that Mars possesses vegetable, and perhaps animal life. but the question that interests humanity is, Are there intelligent beings there? The only important argument in favor of their existence is the presence of the canals. These canals are so long and narrow, straight and uniform, that they look artificial. If they are artificial, it is certain that their constructors possess a knowledge of spherical trigonometry, and considerable skill in the mechanical construction of surveying instruments, implying greater intelligence than that possessed by our ancestors a thousand years ago. It is doubtful if our progenitors in the year 900 A. D. could have built a perfectly straight road three thousand miles long, directed to a definite point, even if it had been across level country.

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[10] Lowell Observatory Bulletin No. 8.

But is the evidence sufficient as yet to warrant us in pronouncing in favor of such intelligent beings? Doubtless the temptation to do so is very strong, but that should not influence our judgment. It is a general principle of science that when two explanations of a phenomenon are possible, we should, other things being equal, choose the simpler. Lowell's maps of Mars look very artificial but we must remember that they are composites of many drawings, such as are given in this article. All the canals shown on the maps are not seen at once; on the contrary, only a very few of them are visible on the same night. It seems to the writer that the arguments both for and against intelligent inhabitants have been materially strengthened during the past few years. It does not seem to him, however, that on either side are they conclusive. The reader must therefore choose for himself between them.

Let us suppose that there are intelligent inhabi-

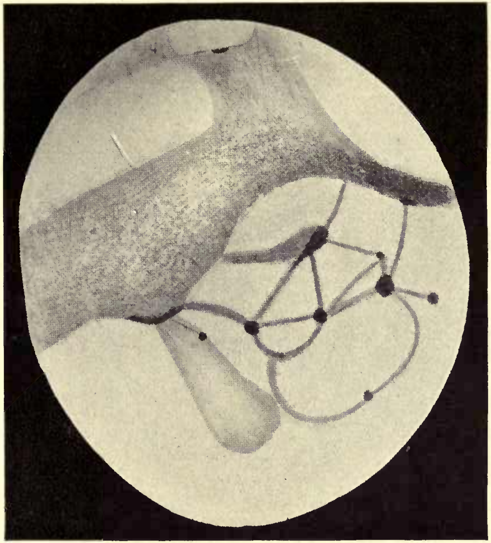

FIG. 10

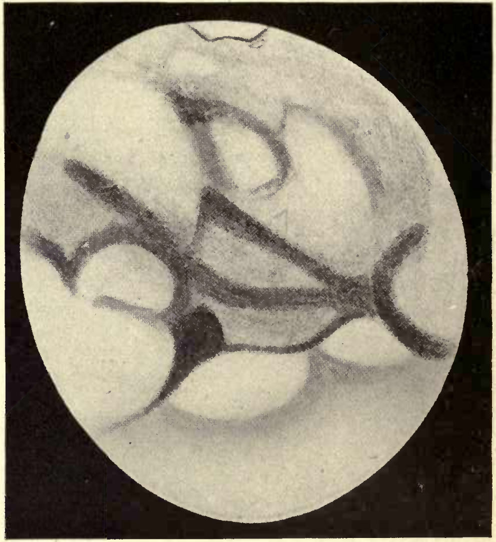

FIG. 11

HOW MARS LOOKS WHEN SEEN UNDER THE BEST POSSIBLE CONDITIONS

From drawings made by Professor W. H. Pickering at Lowell Observatory, Flagstaff, Arizona, during the favorable opposition of the planet in 1894. Scale 1 to 100,000,000 or 1,600 miles to 1 inch. Fig. 10 shows canals and lakes about Solis Lacus; Fig. 11, canals crossing seas south of Syrtis Major. Flattening of the terminator or dark edge of the planet, over seas, is also shown in Fig. 10. Both figures show light shading in lower part of disc, which precedes formation of canals

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tants. One can imagine, in the seasonal transfer of the water across the equator, that a portion of the moisture, condensed from the air each night as a heavy dew, is deposited on the ground and perhaps on sparsely growing and therefore invisible vegetation, in the desert regions. From that rare atmosphere, consisting largely of aqueous vapor, so much may be condensed in the more elevated areas as to flow in invisible channels to the larger canals, causing the vegetation there to develop, and thus become visible. A good deal of the moisture would sink into the soil, but this would the next day be evaporated by the Sun's heat, and continue on its course to the winter pole. This explanation, of course, does not necessarily involve the existence of intelligent inhabitants; but without them the canals would almost certainly in the course of time lose their straightness and artificial aspect.

The other explanation of the canals is that they are due to the same causes that produce those on the Moon. As seen through the telescope they look exactly like them, save that the Martian canals are much longer and somewhat wider. The lunar canals seldom exceed ten miles in length. They radiate from small lakes and join large seas precisely like the Martian areas, and are equally straight and artificial looking in appearance. They wax and wane with the seasons in the same way. The Moon is so near that we can study them to advantage. The foundations of the lakes are minute craterlets; of the canals, fine cracks. As the season progresses, dark areas form about them and later fade out. The explanation offered is that moisture is given out by the cracks, which is later absorbed. This moisture nourishes the vegetation to which the darkening is due. Exactly similar cracks, causing similar vegetational canals, are found in Hawaii. One characteristic canal was estimated by the writer at two or three yards in width, by thirty in length. The terrestrial and lunar canals are certainly produced without intelligent assistance.

In conclusion, we may say that while we have not as yet sufficient information to settle this question definitely, information is slowly accumulating, largely owing to Professor Lowell's indefatigable industry, which will doubtless decide it in time. His observatory is the only one at present specially devoted to securing an answer to it, and it seems almost a pity that some other favorably located observatory should not devote some of its time to the same object.

CHAPTER XIV

DIFFERENT EXPLANATIONS OF THE CANALS OF MARS[1]

Leaving aside the older and now generally discredited explanations that the canals are gigantic water channels, that they are cracks in a universal covering of ice, and that they are grooves cut by colliding asteroids, we will turn to the explanations held as more probable by the astronomers of the present day.

Much of the oldest of these[2] considers them to be caused by narrow ditches, which, crossing the desert regions of the planet, furnish water to vegetation growing along their banks. It is these comparatively broad bands of vegetation, and not the narrow water-channels themselves, which are visible in our telescopes. The chief advocate of this view at the present time is Professor Lowell, who has adopted it as the foundation of his theories of Martian civilization. A serious objection to the hypothesis is the difficulty of forcing water through the canals for thousands of miles, over a comparatively level country. Professor Lowell gets over this difficulty by stating that it is pumped through them artificially. Many astronomers recoil from an artificial explanation, where it is possible to account for the phenomena observed by any natural method.

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[1] Harper's Monthly, 1908, 192.

[2] Science, 1888, **12**, 82.

The difficulty of transporting the water is further enhanced if we consider the fact, which is generally admitted, that the amount of atmosphere we find on Mars does not exceed one-quarter the quantity per square mile of surface that we find upon the Earth. This view is based largely on Professor Campbell's spectroscopic investigations, confirmed by the clearness with which we see the details of the planet's surface. Since gravity upon Mars is but three-eighths of what it is upon the Earth, the atmospheric pressure on the Martian surface cannot exceed three thirty-seconds of our own, or 71 millimeters of mercury. Under this low pressure water boils at 113° Fahr. If the amount of atmosphere on Mars is only one-tenth as much as that on the Earth, which is highly probable, the boiling point of water upon the surface of the planet would be reduced to 84° Fahr. That the daylight temperature of the surface does not differ greatly from our own, we know by the rapidity with which the polar ice-caps disappear on the approach of summer. It would, therefore, seem that the evaporation of water from the surface must proceed with extraordinary rapidity, and the difficulty of transporting it through canals, and supplying sufficient for the needs of vegetation upon the way, must be accordingly greatly enhanced.

Indeed, it would seem necessary to substitute gigantic water-mains for the canals, with a most extended system of supplementary piping. The amount of power required to pump sufficient water to irrigate anywhere between 100,000 and 1,000,000 square miles of surface, through such a system of piping, may be left to any competent hydraulic engineer to compute, with the added statement that most of the water is to be transported to a distance exceeding 1,000 miles.

If we are to insist on a Martian civilization at all hazards, a more defensible explanation of the canals might be founded on the photograph shown in Fig. 1. This photograph was obtained by the writer during the past summer while on a vacation trip in the Azores. It represents a somewhat insignificant hill known as Cabeço Gordo, which was passed on the way to the summit of the volcano Pico, near Fayal.

There is a bush or low tree, known as the urze, which grows on the slopes of the volcano, and which is analogous in character to our pines and spruces. This hill was originally covered with it, but most of it has now been cut down by the shepherds in order to afford pasturage to their flocks. Narrow areas of it have been permitted to stand, however, in order to furnish protection to the animals against the terrific winter winds sometimes occurring at these altitudes.

Similar markings might very readily be produced artificially on Mars, and we are not even obliged to assume that any portion of its surface is of a desert character. It must be remembered that the canals of Mars are not a few feet but several miles in breadth. Imagine that the whole surface of the planet was originally covered with some form of bush or tree, which in the northern and equatorial regions has now been largely destroyed. Its continued presence in the southern regions would account for the so-called seas, while narrow, more or less continuous, strips of it would account for the canals.

The vegetation, both field and woodland, would be supported by the atmospheric circulation, just as it is upon the Earth, and no gigantic engineering feats whatever are required of the assumed inhabitants. Why the inhabitants of Mars should grow their vegetation in these peculiar forms, the writer does not pretend to know, but very likely the same reason that influences the shepherds of Cabeço

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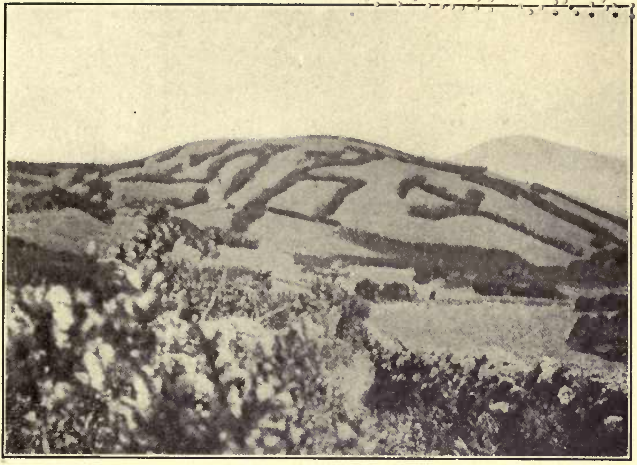


FIG. 1. CABEÇO GORDO, A HILL IN THE AZORES, SHOWING CANAL-LIKE MARKINGS

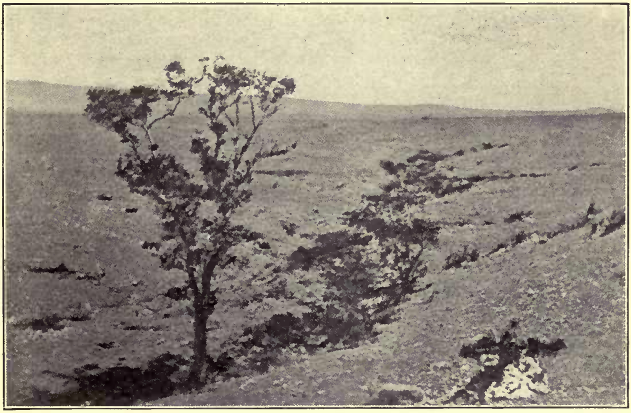


FIG. 5. A CANAL-LIKE MARKING PRODUCED NATURALLY IN THE DESERTS OF HAWAII BY AN ACTIVE STEAM-CRACK

Gordo, protection against severe winter climate, may be the explanation.

But is it necessary to assume a Martian civilization? Astronomers generally think not. The only argument in its favor is the artificial appearance of the drawings of the canal system of the planet. What the public generally does not understand, however, is that while the drawings may look thoroughly artificial, and may be most carefully made, yet that the planet itself, if sufficiently well seen, might not look artificial at all. The statement sometimes made that the canals really consist of straight uniform lines is by no means generally accepted by astronomers. In fact, as we shall presently see, what evidence we have points quite in the opposite direction.

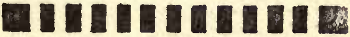
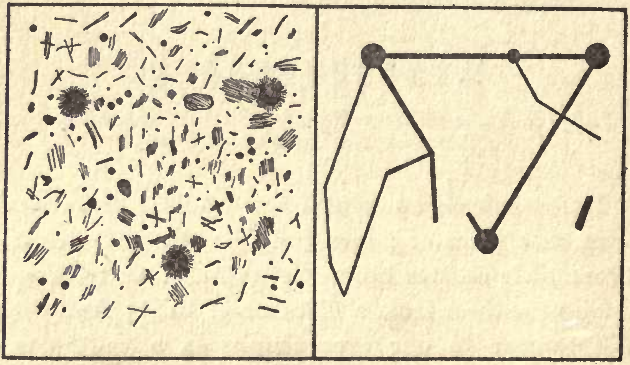


Fig. 2. A Series of Dots Which at a Distance of 30 Feet Looks Like a Continuous Line

If we make a horizontal row of dots or vertical lines on a piece of paper (Fig. 2), the distance between their centres being one-eighth of an inch, and if we view them from a distance of thirty feet, they will appear to our eyes simply as a continuous, uniform, horizontal line. If we scatter a sufficient number of dots and lines irregularly over the paper

(Fig. 3), and view them also from a distance of thirty feet, it will be possible for us, after a careful examination, to see the three chief dots connected as shown by the heavy lines, (Fig. 4). At a suitable distance these lines will appear perfectly straight and uniform. If we approach somewhat nearer, the finer lines will appear. These lines have a very artificial aspect, and yet, if we view the original (Fig. 3) close at hand, we shall see that the drawing really represents nothing but an irregular grouping of spots.

Photographs of fine planetary or lunar detail are much more unreliable than drawings, because they have to be on so small a scale in proportion to what is known to photographers as the "grain"



FIGS. 3 AND 4. IRREGULAR MARKINGS SUCH AS ARE SHOWN IN FIG 3, WHEN SEEN FROM A DISTANCE OF 30 FEET, RESEMBLE THE CANALS OF FIG. 4

of the plate. This grain is a sort of irregular background, which becomes very conspicuous as soon as the plate is sufficiently enlarged. Atmospheric difficulties and irregular motions of the driving-clock of the telescope are also much more serious to the photographer than to the visual astronomer. For these reasons astronomers generally consider, that it was a great triumph for the photographers of the Lowell Observatory to be able to get any indications of the canals whatever upon their plates. As far as a detailed study of the planet's surface is concerned, however, the Lowell drawings are of much more value than the Lowell photographs.

As to the so-called doubling of the canals, most astronomers simply decline to admit the existence of the phenomenon, on the visual and photographic evidence so far presented. That out of several hundred canals one or two might be double from merely accidental causes is not denied, but the demonstration of the duplication of any large proportion, such as one-fourth, as claimed by Professor Lowell, is awaited with interest.

But if we deny that the canals are artificial, how then can they be explained? The alternative hypothesis,[3] and the one which it is believed from the writer's private correspondence is generally preferred by those astronomers interested in Mars, is

[3] **Popular Astronomy, 1904, 12, 439.**

that the canals are due to volcanic cracks lying between craterlets on the Martian surface. Water vapor escaping from these craterlets and cracks nourishes the vegetation growing along their sides, and it is this vegetation which is visible in our telescopes.

This latter view has the distinct advantage that it also explains the canals on the Moon, which, as seen through a small telescope, are indistinguishable from those on Mars. They also go through the same changes and transformations in the course of a lunation that the Martian canals do in the course of the Martian year, and differ from them only in the fact that they are on a much smaller scale. Through a large telescope, with good atmospheric conditions, the craterlets and cracks about which the lunar lakes and canals are formed can be distinctly seen, and the gradual transformation of a crack into a canal has been watched, and the rate of growth of the latter measured.[4] Through a small telescope the lunar canals, like the Martian ones, appear straight and perfectly uniform. Through a large glass, on the other hand, irregularities of outline appear, and marked variations in the depth of color.

Similar natural canals formed about terrestrial

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[4] Annals Harvard College Observatory, **53**, 78. Memoirs American Academy, 1906, **13**, 176.

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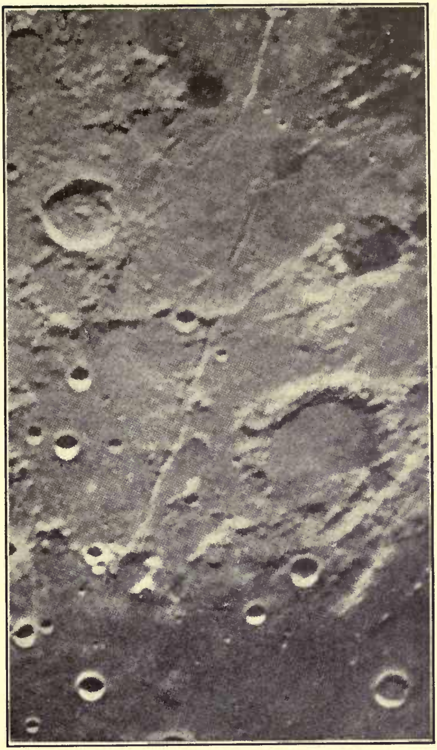

FIG. 6. THE ARIADÆUS RILL, A STRAIGHT VOLCANIC CRACK UPON THE MOON, 150 MILES IN LENGTH

(Photographed at Yerkes Observatory with 40-inch telescope)

volcanic cracks have been studied and photographed in Hawaii. See Fig. 5.[5] This view represents a portion of the desert extending to the south of Kilauea. The only vegetation growing upon it consists of trees, low bushes, and ferns, which stretch across it in long, narrow, straight lines, following the course of the steam cracks, whose exhalations furnish the necessary moisture on which the existence of the vegetation depends.

Stretching across Fig. 6 is shown the Ariadaeus rill, a volcanic crack upon the Moon 150 miles in length. If it were still giving out steam, we should doubtless have here a straight lunar canal quite comparable in size to many of those found on Mars. About one thousand of these rills, most of them much smaller than this one, are now catalogued upon the Moon.

The objection that most astronomers feel to the admission of the existence of civilization upon Mars is not, it seems to the writer, a sort of jealousy of the other planets, such as Professor Lowell has suggested and a wish that intelligence should be confined to our Earth. On the contrary, trustworthy evidence of its existence would certainly be welcomed by them, as by everyone else, not only with pleasure, but with wild enthusiasm. Their feeling, I believe, is rather that the four planets, Venus, the Earth, the Moon, and Mars, are all of about the same size and are situated at similar distances from the Sun. Their surface conditions must therefore bear a general resemblance to one another. Life is so persistent, and will exist under such varied conditions, that it is not surprising that it should be found on all of them. Indeed, as we have seen, we have already pretty strong visual evidence that it does exist on two of them besides the Earth. As compared with vegetation, it seems probable that human life, or its planetary equivalent, would have much more narrow limits. Vegetable life beneath the sea, for instance, is, as we all know, very luxuriant. The possible limits of civilization are still more narrow than those of human life.

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[5] **See Figure 5, facing p. 150.**

Under the reduced atmospheric pressure and probable almost total lack of free oxygen upon Mars, we can still see no reason why vegetation should fail to exist. But is it likely that civilization should be found there also? We do not definitely deny that some form of civilization under these circumstances might be possible, but why invoke its aid to explain the various observed phenomena, such as the canals, if we can furnish a better, or even nearly as good, explanation of them by some other hypothesis?

The physical conditions on Mars are in many ways intermediate between those found upon the

Earth and the Moon, and it seems plausible that the life existing upon it should similarly be of a higher type than that found on the Moon, and of a lower type than that found at present on the surface of the Earth. Even if the physical conditions, as we understand them, were equally favorable with those on the Earth, civilization would by no means be a necessary consequence. Had it not been settled by Europeans, the United States would still be a wilderness. How much less should we hasten to accord civilization to a planet of which we know little, except that if we were transported there ourselves, we should instantly die.

CHAPTER XV

SIGNALLING TO MARS[1]

Although this computation was first made by the writer for his own amusement, nearly twenty years ago, it had never seemed to him of sufficient interest or importance to the astronomical world to publish it anywhere, and he would not do so now, had not his definite statements on the subject been directly called in question. By the term "possibility of communication with a remote planet" the writer means that if a portion of the human race, with their present knowledge and appliances were removed to that planet, and could live there, that it would be possible to communicate with them. Whether there are intelligent beings on Mars or on any other planet, the writer does not know. That is an entirely separate question, and has nothing whatever to do with the case.

The constants required in our computation are as follows:—

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[1] Popular Astronomy, 1909, 17, 495.

S=Mean distance from the Earth to the Sun .... 92,900,000 miles
M=Mean distance of Mars to the Sun ....141,500,000 miles
D=Mean diameter of the Sun from the Earth......... 1,922″
L=Stellar magnitude of the Sun .... −26.83 miles

The computation is made when Mars is situated in quadrature with the Sun. In this position its mean distance from the Earth, M, is 108,000,000 miles. Let us imagine a mirror erected upon the Earth of such a size that the whole disk of the Sun can be seen in it from Mars. Let d be the diameter of the Sun as seen in the mirror, and l its magnitude. Then,

$$d = \frac{DS}{S + M} = 888''$$

and

$$1 = 2.5 \ (\log \ (S+M)^2 - \log S^2) + L = -25.15$$

Let us now imagine this mirror so reduced in size as to reflect a circular beam whose diameter is only $\frac{1}{1{,}000{,}000}$ of that of the Sun's disk. As seen from Mars the diameter of this beam will be

$0''.00089$, and its brightness, which will be reduced 30 magnitudes, 4.85. The diameter on the Earth of such a beam will be a trifle less than half a mile. Therefore, allowing for absorption and an inclined mirror, the sunlight reflected from an area of mirrors a little over half a mile square would appear to Mars, when in quadrature, of the brightness of a star of the fifth magnitude. When Mars was forty-five degrees from opposition, and its distance from the Earth was 61,000,000 miles, such a beam would be brighter than the fourth magnitude.

This light would, of course, be very conspicuous from Mars with the naked eye, were it not for the brightness of the Earth itself. This materially modifies the problem. By holding a mirror so as to cover half of the area of a 6-inch objective, and by so doing projecting the image of a star of the 2.8 magnitude upon the disk of the Moon, the star was found to be just visible with a 2.5-inch eye-piece. With a higher power and steadier mirror, much better results would have been obtained, but on this basis a 24-inch objective should be able to show a star of the 6.5 magnitude when projected upon the disks of the Earth or Moon. The object of using a higher power would be to reduce the light of the Moon without diminishing that of the star. With four times the power, a signal of the 8.0 magnitude should readily be detected, even after allowing for some magnification of the star image itself.

It therefore appears not only that the plan of signalling to Mars by the system proposed is "scientifically plausible," but that if it were adopted, we should produce a signal that would be three to four magnitudes, that is 16 to 40 times brighter than necessary, and would, therefore, be dazzlingly conspicuous to Martian observers, if they were intellectually and physically our equals.

In closing, the writer would only add that this plan of signalling to Mars is not now, and never has been (as is shown by a large portion of the contemporary press), advocated by the writer, until after we shall have obtained more definite information that there are intelligent inhabitants upon Mars.

CHAPTER XVI

THE CANALS OF MARS[1]

In the issue of the *Scientific American* of July 10th, a correspondent argues that the discovery of the gradual shifting of position of some of the canals of Mars helps to strengthen, instead of weakening, the theory of irrigating ditches. It does undoubtedly strengthen all the theories of the canals based on the idea that they are strips of vegetation, and it also incidentally strengthens the idea that their formation and maintenance may be due to the efforts of intelligent life upon the planet. But it weakens the explanation of irrigating ditches, as compared with some of the other theories.

Let us now consider some of these, which assume the existence upon Mars of intelligence analogous to our own. Let us first discuss one of those based on the idea that the lack of water is really the chief necessity felt upon the planet. According to this theory, invisible water vapor is evaporated by the heat of the sun from the snowy pole in the springtime and transported by the planetary circulation to the other pole, where the sun is setting for the long winter night. Here the vapor, which forms a much larger proportion of the planet's atmosphere than with us, is condensed as snow, a constant distillation going on by the sun's heat from one pole to the other, and then back again, every year. During the nighttime a portion of this traveling vapor is deposited as fog over the level regions. In many cases these elongated areas may lie in slightly depressed regions or valleys, where the fog would naturally accumulate of itself. In the early morning on Mars, where the sun is rising, we can sometimes see the fog clear away, and it is in these moistened regions that the vegetation springs up and forms the so-called canals.

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[1] **Scientific American, 1915, 113, 249.**

But while the lack of water appears at first sight to be the chief necessity of Mars, judged by terrestrial standards, yet such may not really be the case at all, and we might suggest that other needs may be much more pressing. Besides water, vegetation requires several solid constituents, the chief of which, applied as fertilizers, are alkalies, phosphates, and nitrates. On account of its small atomic weight, nitrogen in the gaseous form must certainly be rather rare on Mars. We are just beginning on the earth to have to use our atmospheric nitrogen as a source of nitrates for fertilizers. It may easily be that the Martians have not sufficient quantities of it or of some other of these solid constituents to enable them to fertilize the whole surface of their planet, and they therefore distribute their fertilizer as widely as they can in those places where it will do the most good, occasionally shifting their crops to fresh regions of the planet.

Still another theory, also involving artificial direction, may be based on the fact that, besides solids and water, vegetation requires two gases for its existence—oxygen and carbon-dioxide. While a very important part of the work of plant life is the breaking up of the latter gas and the evolution of free oxygen, yet oxygen is itself consumed in considerable quantities by vegetation, just as it is by animals. We know that there is not very much atmosphere on Mars, and oxygen must be scarce.

But, besides the oxygen, it is quite possible that the carbon-dioxide, too, may be lacking. On our own earth this necessary food for vegetation is provided, not as is sometimes supposed, chiefly by the breathing of the animal world, but by our more or less active volcanoes. Animal life, indeed, furnishes only an insignificant fraction of the total supply. Mars is an ancient world, and any volcanoes that it formerly possessed may now very likely be entirely extinct. In such a case all the carbon-dioxide required by vegetation must be supplied by the animal world, by combustion, or possibly by some other chemical process. To maintain the proper balance between animal and vegetable life, it is clear that the latter must be more or less limited. All useless vegetation would be destroyed, and such as was left would only be permitted to grow in the most favorable and necessary places. Indeed, we find that the canals which when they first appear are very wide, gradually narrow as the season progresses, and this very narrowing may itself be a visible indication to us of the activities of the Martians!

It is generally believed that the southern hemisphere of Mars is situated at a slightly lower level than the northern one. This is indicated by observations of the Martian terminator. This difference of level has been given as the explanation for the observed fact that most of the Martian vegetation is confined to the southern hemisphere. This explanation would be particularly applicable if there were a shortage of carbon-dioxide on the planet, as it is well known that this gas always tends to collect, on account of its high specific gravity, in any deep depressions of the earth's surface.

Each one of these theories accounts for the canals found upon the planet and for their distribution chiefly in the northern hemisphere, as well as for their shifting and narrowing with the progress of the seasons. If we once admit the existence of intelligent life on Mars, since we have no means whatever of knowing what are their chief needs, it becomes useless for us to theorize further upon their reasons for constructing the canals, otherwise than to say that they indicate a shortage of supplies for vegetation.

Whichever need may be most felt, whether water, nitrogen or carbon-dioxide, it appears that the canals are calculated to meet it, and are what we might ourselves construct or plant under similar circumstances.

All of these theories avoid the necessity of enormous conduits and the expenditure of an amount of work in pumping, which has recently been estimated by an expert adherent of the pumping hypothesis at 2,500,000,000 horse-power, or four thousand times that of Niagara Falls.

The reason that the writer stated in a former paper, that the irrigation conduit theory was not strengthened by the shifting the canals, was that the number of conduits would have to be increased if the canals shifted. This does not, of course, disprove the conduit theory, but certainly does not strengthen it, as compared with the other theories explaining the canals, where no such added construction is necessary.

CHAPTER XVII

MARS—THINGS KNOWN AND SURMISED[1]

It is a rather difficult matter to distinguish what is known from what is surmised about any subject, but if we define what is known about Mars as meaning what is generally believed about it by professional astronomers, and what is surmised as what at the present time seems most probable, the writer thinks that present Martian views may be summarized rather briefly.

We have, first, the astronomical data, which are certainly known, and are approximately as follows: The distance of the planet from the sun is one and a half times as great as that of the earth. Its year is 687 of our days, or nearly two of our years. Its orbit is very eccentric, so that it is sometimes much nearer to the sun than at others. Its diameter is a little over forty-two hundred miles. Its mass is one-ninth, and its surface gravity about two-fifths, that of the earth. This latter quantity is most important in determining its supply of water and atmosphere, and therefore its habitability. The inclination of its equator to its orbit is practically the same as that of the earth. Hence its seasons are similar, except that they are nearly twice as long as our own. Its period of rotation upon its axis, that is to say, its day, expressed in terrestrial units, is twenty-four hours and thirty-seven minutes.

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[1] Cosmopolitan, Oct., 1909, 616.

Most astronomers would probably accept the following statements as true: The planet possesses white polar caps, which increase in winter and diminish in summer. These are due to ice. When they are melting most rapidly they are surrounded by a dark ring of water, which soon disappears. This is the only water visible upon the planet. The melting ice fixes the temperature at this time, which is 32° Fahrenheit. The atmosphere is extremely rare. This involves great extremes of temperature, a rapid evaporation of the water in the daytime, and a very rapid deposition of dew or frost at night. The climate from our standpoint must, therefore, be extremely disagreeable, even at the equator. While never very hot, it must at night be extremely cold. The atmosphere is much more rare than upon our highest mountain summits, and would, therefore, be quite unbreathable by terrestrial animals. Clouds have been observed floating over the surface of the planet, and their speed and direction measured. Except at sunrise and sunset they are of rare occurrence, although they are observed more frequently at the time of the melting of the polar caps.

The dark surface markings of the planet consist of the so-called seas, canals, and lakes, which last are also known as oases. The light surface markings consist of the so-called deserts, causeways, and white spots. Those astronomers who attempt to explain them at all consider them to represent different densities of vegetation. The writer believes the white spots to be due to a form of vegetation equivalent to our flowering plants. These spots appear for a few weeks in the summer time near the tropics.

The above summarizes practically all that we know, and all that we may properly surmise, with regard to Mars. To those who are in any way interested in the planet, the matter of most vital importance, at present, is the question, Are any of these surface markings artificial? Certainly they may be. We have no definite proof to the contrary, but any statement at the present time ascribing them directly to intelligent beings must be clearly understood to be no better than a speculation.

What then can we do to settle this question? To many persons this is a matter of serious importance. All who have seen the canals clearly, must admit that they have an artificial aspect. That is to say, they are not sinuous in shape, but are fairly straight. Moreover, they are of pretty uniform breadth and density. This would all appear very favorable to an artificial origin, but unfortunately it so happens that there are canals upon the moon which appear equally straight and equally artificial, although much smaller. They also appear and disappear with the seasons. The lunar canals certainly cannot be artificial. Similar canals on a still smaller scale have been found in the Hawaiian Islands. They are due to vegetation along volcanic cracks crossing a desert region. The steam emitted from these cracks supports the vegetation, which would otherwise wither and die. The question at once arises whether it is possible that the lunar and Martian canals are due to this same cause.

Few astronomers now deny the existence of the Martian canals. The question for us to settle is not, Do they exist? but, How do they look? To settle this does not require a gigantic telescope, but it does require an especially good atmosphere. Such an atmosphere can only be found in a low latitude. A five-inch telescope in Jamaica shows much finer planetary detatil than a fifteen-inch telescope in Cambridge. A large telescope erected in our northern states would be absolutely useless for the purpose in hand. Indeed, it would probably be undesirable in any location. Perhaps the best results would be obtained with a moderate-sized telescope of about twenty-four inches aperture, which is the size of the instrument which has been erected by Prof. Percival Lowell in the clear atmosphere of Flagstaff, Arizona. Given such an instrument in an ideal locality, how should it be used?

A man who has good eyesight, or who is a skilful astronomer, is not necessarily a good artist. This point has been quite overlooked by the public hitherto. Yet it is of the utmost importance if we wish to know exactly how the canals appear. To settle this question a number of experienced astronomers should be invited to sketch the canals as seen by them through this same telescope, located under these extremely favorable conditions. Astronomers with some little experience in sketching planetary or lunar details should be selected by preference. Besides the astronomers, a number of artists skilled in miniature work should also be invited to study the planet. Probably none of these men would secure results of much value during the first week of their observations, because it requires a special training acquired only by practice to enable one really to understand what he does see in this class of work. During the second week of this work, however, more valuable results would be secured.

Studies of both the lunar and Martian canals should be made by each observer, and finally the best results of each man should be selected and published. When this has been done, then not only astronomers, but the public at large, will have a fair opportunity to judge for themselves of the appearance of the detail of the planet, and decide whether or not it is probable that the canals of Mars are the work of intelligent beings. This is certainly the next step that should be taken in our investigation of this most interesting planet.

INDEX

Associated observers, 19.
Atmosphere, 12, 20, 59, 126, 148.

Blue color of water, 40, 43, 48, 57, 99, 100.

Canals, Description of, 83, 86.
  Duplication, 58, 67, 89, 113, 138, 153.
  Explanation of, 14, 42, 43, 58, 76, 87, 95, 103, 108, 111, 133, 138, 145, 147, 149, 162, 170.
  Lunar, 105, 109.
  Shifting, 18.
  Width of, 19, 84, 89, 104, 134.
Changes visible, 18, 39, 42, 48, 58, 84, 97, 99, 142.
Climate, 13, 78.
Clouds, 13, 17, 55, 57, 58, 60, 128, 130.
Color changes, 38, 45, 57, 81, 100, 118.
Colors visible, 18, 26, 45, 57, 79.

Data regarding planet, 11, 120, 167.
Depressions on terminator, 101.
Deserts, 14, 45.

Ellipticity of disc, 59.

Facts regarding planet, 11, 57, 120, 167.

History of discoveries, 64, 131.
Horse power for irrigation, 15, 166.

Lakes, 19, 58, 62, 83, 86.
  Lunar, 109, 137, 145.
Life, Intelligent, 92, 143, 155, 164.

Marshes, 12, 17, 81.
Meteorology, 78.

Photographs of planet, 129, 135.
Polarization, 43, 99.

Seas, 14, 44, 72, 79, 124.
Signalling to Mars, 158.
Snow, 12, 21, 32, 46, 60, 68, 116, 124.

Telescopic apertures, 131, 170.
Temperature, 24, 75, 127.

Vegetation, 14, 43, 45, 101, 108, 130, 133, 134, 142.

Water transferred across planet, 15, 74.

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